

# THE AMERICAN MINERALOGIST

JOURNAL OF THE MINERALOGICAL SOCIETY OF AMERICA

Vol. 26

NOVEMBER, 1941

No. 11

## IGNEOUS ROCKS OF THE MERRYMEETING LAKE AREA OF NEW HAMPSHIRE

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### ABSTRACT

The Merrymeeting Lake area, like several other small areas in central New Hampshire, has a considerable variety of igneous rocks grouped together. Rock types include, from oldest to youngest, leucorhyolite, diorite-gabbro, granodiorite, granite, granite porphyry, and several dike rocks.

The leucorhyolite may be extrusive, but the other rocks are intrusive. The intrusions cut sharply across the foliation and contacts of the older rocks. They are mainly round or oval in ground-plan. Field relations indicate the cauldron subsidence method of intrusion, which is the same as that in near-by areas.

Evidence supports the correlation of these rocks with the White Mountain magma series of possible Carboniferous age.

The variety of rock types indicates considerable magmatic differentiation. Similarity to other areas of White Mountain magma series probably indicates similar differentiation.

INTRODUCTION<sup>1</sup>

An important development in recent studies in New Hampshire (mainly by Billings and his students) has been the demonstration that the igneous rocks may be grouped, on the basis of age, structural relationships, and petrographic characters, into several magma series. The White Mountain magma series of possible Carboniferous age is perhaps the most interesting because of the extensive differentiation and the unusual rock types and structures. Characteristically in this series, rock types of considerable variety are grouped in rather restricted areas. Most of these areas have been described recently, but the Merrymeeting Lake area has not been described previously.

The reasons for assigning these rocks to the White Mountain magma series will be given more fully after the descriptions of the rocks.

## GENERAL SETTING

The Merrymeeting Lake area is a mass of White Mountain magma series rocks which, like the Ossipee Mountains (Kingsley, 1931), the Belknap Mountains (Modell, 1936), Red Hill (Quinn, 1937), a small area of syenite at the Rattlesnakes just northwest of Squam Lake, and Green Mountain, rises above the lowland of Lake Winnepesaukee. The Merrymeeting Lake area is about as large as the Ossipee Mountains and the Belknap Mountains (Fig. 1). It is less complicated than the Belknap Mountains, however, and is not so definite a topographic unit as either.

## OLDER ROCKS

*Metamorphic Rocks*

The older rocks are lime-silicate rocks and schist, both of sedimentary origin. On the basis of lithology and structure the schist is correlated tentatively with the early Devonian Littleton formation of the Littleton, New Hampshire, area (Billings, 1935; Billings and Cleaves, 1934). The lime-silicate rock may be a member of the Littleton formation or it may be older.

The lime-silicate rock consists largely of diopside, actinolite, quartz, plagioclase, zoisite, and calcite. There are also beds of mica schist. The foliation generally parallels the bedding. Small folds are common.

The lime-silicate rock grades upward into thin-bedded quartz-mica

<sup>1</sup> The senior author while studying the Wolfeboro area discovered an area of White Mountain magma series rocks extending southward into the Alton quadrangle, which quadrangle is being studied by the junior author. Because the rocks in the two quadrangles are so definitely a unit it was decided to prepare a joint paper describing them. The senior author did the field work in the Wolfeboro quadrangle, north of Lat. 43° 30', the junior author worked the area to the south, and several days were spent in the field together. The laboratory work was done by the senior author at Brown University. The senior author's work was supported by a grant from the Bache Fund of the National Academy of Science.



schist of the Littleton(?) formation. A small mass of slabby quartzitic schist with many small flakes of graphite isolated at the top of Copple Crown Mountain is of unknown relation to the other metamorphic rocks. The foliation of the schist is generally parallel to the bedding, and both are considerably contorted in the southern part of the area, although of

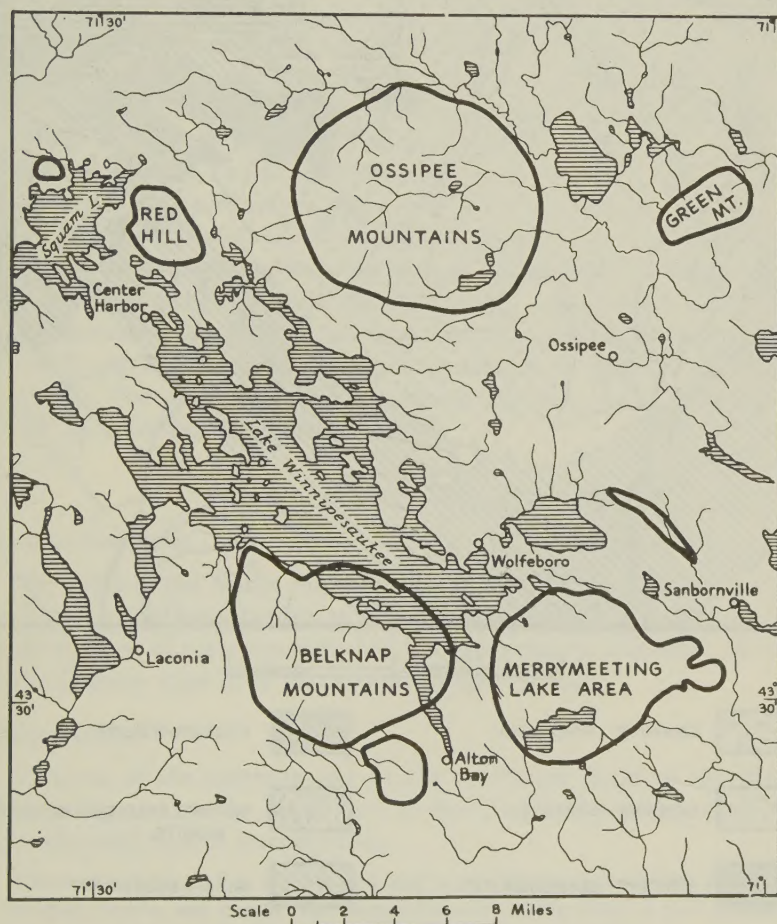


FIG. 1. Areas of the White Mountain magma series in the Winnepesaukee region of New Hampshire.

simpler structure to the north. The detailed structure of the metamorphic rocks has not been determined, but the rocks of the White Mountain magma series are known to cut sharply across the foliation. The cross-cutting relationship is further shown by the way in which the Conway granite cuts across the contact of the schist and the Winnepesaukee quartz diorite (Fig. 2).

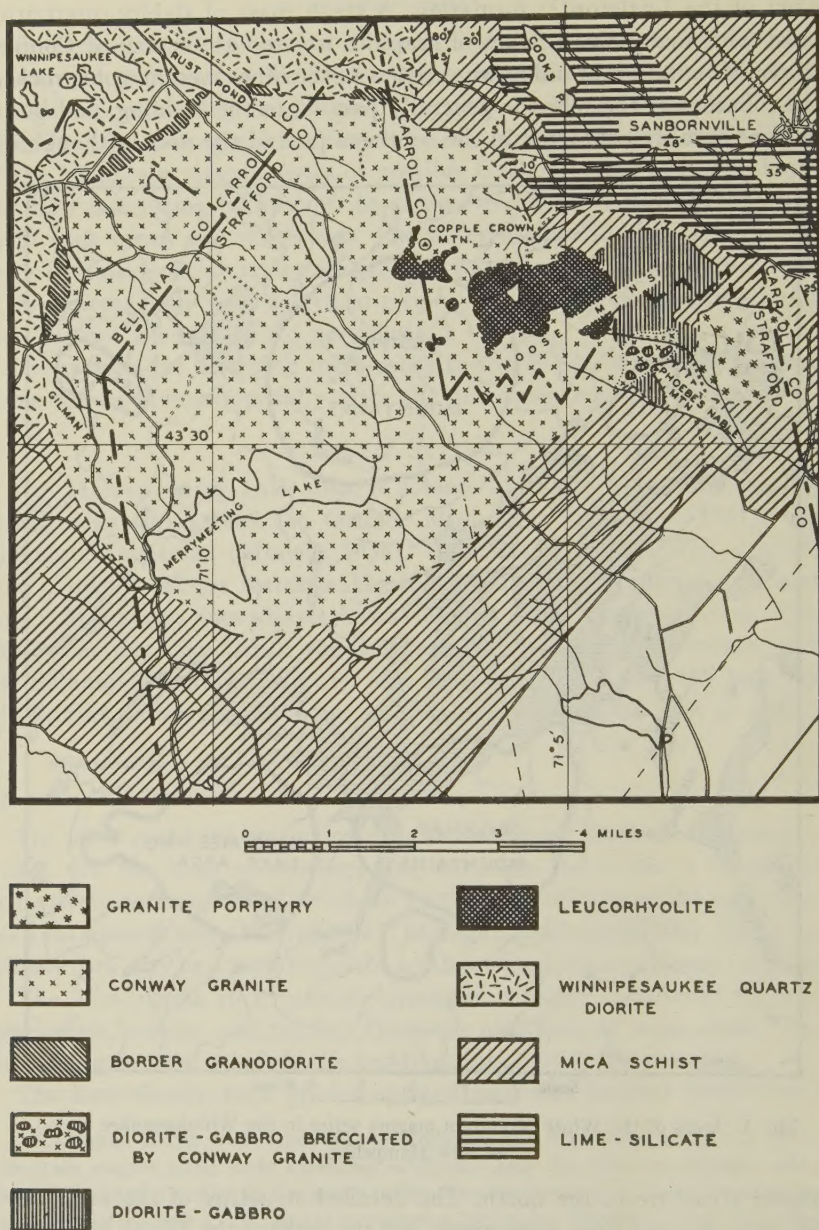


FIG. 2. Geologic map of the Merrymeeting Lake area of New Hampshire.



### *Winnepesaukee Quartz Diorite*

The northwest part of the area is underlain by the Winnepesaukee quartz diorite, which is a member of the New Hampshire magma series of probable late Devonian age (Billings, 1935). It is one of the largest intrusions in this part of New Hampshire, and the Winnepesaukee lowland, which is one of the largest topographic features in New Hampshire, is caused by the more rapid erosion of this rock. It is chiefly quartz diorite, or tonalite, but in places it is granite or granodiorite. Although usually scarce or absent, here and there orthoclase or microcline constitutes up to 40 or 50 per cent of the rock. Considerable quartz is usually present and shows abundant cracks and wavy extinction. Biotite is the main or sole dark constituent. On several islands in Lake Winnepesaukee, especially Bear Island and Mark Island, hornblende is present. Accessories are zircon, apatite, iron ore, sphene, and epidote. At many places a rather faint almost vertical foliation trends almost north-south. The quartz diorite tends to be concordant with the foliation of the schist.

Small pegmatite and aplite dikes are abundant at most outcrops of this rock. The pegmatite usually contains feldspars, quartz, micas, and rarely hornblende, beryl, or tourmaline.

## WHITE MOUNTAIN MAGMA SERIES

### *General Statement*

The rocks of the White Mountain magma series in the Merrymeeting Lake area range from gabbro to granite and from coarse-grained to fine-grained. Most of them are intrusive, but some may be extrusive. Granite of the Conway type is by far the most abundant rock.

### *Leucorhyolite*

On some of the summits and on the northwest slopes of the Moose Mountains, and on the upper part of the Copple Crown Mountain are extensive outcrops of leucorhyolite.

This rock is light gray to flesh or pink and is generally porphyritic with phenocrysts of feldspar, biotite, and quartz. The phenocrysts are usually about 3 to 4 millimeters across and may be up to 8 millimeters across. The structure is massive.

The main constituent is micropertthite, which is present both as phenocrysts and in the groundmass. The groundmass is mainly micropertthite and quartz, in certain places in rude intergrowth. Oligoclase ( $An_{12-19}$ ) occurs as phenocrysts and in the matrix. Biotite, the main mafic mineral, has the following optical properties: biaxial negative;  $\beta$  and  $\gamma = 1.652 \pm .001$  to  $1.646 \pm .001$ ; Y and Z=brown, X=light yellowish-brown; 2V very small. Green amphibole similar to that in the Conway granite is sparse. Accessories are iron ore, zircon, apatite, sphene, and allanite. The mode of the rock is given in Table 1.

TABLE 1. MODES OF MAIN ROCK TYPES IN THE MERRYMEETING LAKE AREA OF NEW HAMPSHIRE

	Diorite-gabbro			Range of diorite- gabbro	Border grano- diorite Wo 24	Conway granite Wo 32	Conway granite border phase Wo 23	Leuco- rhyolite Wo 99	Granite por- phyry Wo 90
	Wo 58	Wo 63	Wo 73						
Microperthite			11	0-15	8	55	42	59	51
Plagioclase	52	63	64	50-81	57	20	36	24	13
Quartz		1	8	0-13	11	22	15	15	32
Biotite	4		7	0-7	6	3	6	2	3
Amphibole		24	4	0-34	16		1		
Pyroxene	30		4	0-30					
Magnetite	9	2	2	1-9					
Sphene		2		0-2					
Accessories				0-2	2				1
Alterations; chlorite, etc.	5	8		0-8					
	100	100	100		100	100	100	100	100

Wo 23—Small abandoned quarry 1.9 miles southwest of Rust Pond.

Wo 24—1.3 miles southwest of Rust Pond, just south of county line.

Wo 32—Just north of the road corner which is 2.0 miles southwest of Rust Pond.

Wo 58—East end Moose Mountains, 0.8 mile north of Phoebe's Nable Mountain.

Wo 63—South slope of Phoebe's Nable Mountain, 0.2 mile south of summit.

Wo 73—North slope of Moose Mountains, in northwest part of diorite-gabbro area.

Wo 90—Brook bed, near southwest edge of granite porphyry area.

Wo 99—Just west of summit of Copple Crown Mountain.

Similar rocks in other areas of the White Mountain magma series have been described as volcanics. These rocks may also be extrusive, but there is no flow structure or other good evidence of volcanic origin.

The leucorhyolite is older than the Conway granite, as indicated by inclusions of it in the Conway granite on Copple Crown Mountain and near the main summit of the Moose Mountains. Its relationships to the other rocks are not shown, except that a few inclusions of a similar rock have been seen in the gabbro. Probably the leucorhyolite is the oldest in the White Mountain magma series. In other areas of the White Mountain magma series, rhyolitic and other types of extrusions are commonly the oldest of the series (Chapman, 1940, p. 209).

#### *Diorite-gabbro*

On the east end of the Moose Mountains and on the slopes of Phoebe's Nable Mountain are outcrops of diorite and gabbro. The rock is quite variable in composition and texture, but all types seem to belong to the



same intrusion. This rock is intrusive into the schist, is perhaps intrusive into the leucorhyolite, is intruded by the Conway granite, and is probably intruded by the granite porphyry. It appears to be the oldest of the White Mountain magma series rocks with the exception of the leucorhyolite.

The rock ranges from gray to dark gray in color. Near the top of the Moose Mountains it carries considerable pinkish potash feldspar. On the southeast slope of the Moose Mountains, near the border of the diorite-gabbro mass, it contains considerable pale green pyroxene. A dark heavy type occurs on the south slope of Phoebe's Nable Mountain and on the northeast slope of the Moose Mountains. The grain size varies from about 1 to 3 or 4 millimeters. The rock is usually massive, but the finer diorite tends to have slabby jointing. In general, the fine-grained dioritic types are intrusive into the coarser gabbroic types. All types seem to have been intruded as a liquid.

The main constituent is plagioclase. It ranges from  $An_{36}$  to  $An_{55}$ , and much of it is near  $An_{50}$ . Here and there micropertite is present in large irregular grains.

Amphibole, the most abundant mafic mineral, varies in optical properties as is indicated by the following types: (a)  $\alpha = 1.664 \pm .002$ ,  $\beta = 1.679 \pm .001$ ,  $\gamma = 1.689 \pm .001$ ; 2V large, X=light brown, Y=brown, Z=dark brown,  $Z > Y > X$ ;  $Y = b$ , maximum extinction angle in vertical zone =  $27^\circ$ ; dispersion moderate; (b)  $\alpha = 1.634 \pm .002$ ,  $\beta = 1.647 \pm .001$ ,  $\gamma = 1.656 \pm .001$ ; 2V large, X=almost colorless, Y=light green, Z=light green;  $Y = Z > X$ ;  $Y = b$ ; maximum extinction angle in vertical zone =  $29^\circ$ ; dispersion moderate.

Pyroxene is present sparingly in several places and comprises about 30 per cent of the rock at the east summit of the Moose Mountains. There it is intergrown in ophitic texture with plagioclase. It has the following optical properties:  $\alpha = 1.686 \pm .001$ ,  $\beta = 1.702 \pm .001$ ;  $\gamma = 1.724 \pm .002$ ; 2V large; maximum extinction angle in vertical zone =  $38^\circ$ ; almost colorless.

Biotite, present in most specimens, has optical properties near:  $\beta$  and  $\gamma = 1.647 \pm .001$ , 2V very small, X=pale yellow, Y and Z=dark reddish-brown.

Quartz is present as scarce interstitial grains, many of which are rather large considering that the quartz makes up a very small portion of the whole rock. A few small patches of micropegmatite were seen.

Accessory minerals and alterations include: iron ore, abundant needles of apatite, sphene, zircon, epidote, pyrite, muscovite, chlorite, limonite, calcite, and serpentine.

Several representative modes of this rock are given in Table 1.

### *Intrusion Breccia*

To the north and west of Phoebe's Nable Mountain is an area of intrusion breccia, a fine-grained rock of granitic composition, probably a phase of the Conway granite, with inclusions of dioritic composition which range from small pieces a few inches across to blocks several feet across. Some of these dioritic blocks are similar to the diorite-gabbro types; others are porphyritic and not found in the diorite-gabbro.

The porphyritic diorite has a fine-grained groundmass and plagioclase phenocrysts up to 2 or 3 millimeters across. Plagioclase ( $An_{40-45}$ ) comprises about three-quarters of the rock and is somewhat zoned. Amphibole, which comprises about a quarter of the rock, has the following optical properties:  $\alpha = 1.649 \pm .002$ ,  $\beta = 1.668 \pm .001$ ,  $\gamma = 1.675 \pm .001$ ; 2V about

60°; X=light yellowish-brown, Y=brownish-green, Z=green;  $Y=Z>X$ ;  $Y=b$ , maximum extinction angle in vertical zone=28°. Accessories include iron ore, sphene, and apatite. Small inclusions of this type of rock are found at many places in the large area of Conway granite and at many occurrences of Conway granite in other parts of New Hampshire; it is believed to be a differentiate formed below the present surface and carried up by the invading Conway granite.

The breccia contains inclusions of schist also. On Phoebes Nable Mountain it appears that first the diorite invaded the schist and enclosed blocks of it, and that later the granite came in and enclosed blocks of both.

This breccia resembles somewhat the intrusion breccias of the Belknap Mountains (Modell, 1936, pp. 1899–1900) and is probably genetically related to them. The ring-dike structure, so well developed in the Belknap Mountains, is generally considered to involve tensional collapse and that would probably favor brecciation.

### *Border Granodiorite*

Along the northwest margin of the large Conway granite mass is a discontinuous outcrop of granodiorite. It intrudes the Winnepesaukee quartz diorite and is itself cut by the Conway granite. Brecciation by the Conway granite is exposed on the hill just east of Rust Pond and along the brook about  $1\frac{1}{2}$  miles east of Rust Pond. The arcuate shape of the granodiorite outcrop suggests the ring-dike structure, but the shape of the inner contact of the granodiorite has been determined by the later Conway granite intrusion rather than by the granodiorite intrusion itself. The original shape and extent of the granodiorite are unknown. The many small inclusions of granodiorite in the Conway granite to the south and east of this arcuate mass suggest that the granodiorite may have been much more extensive than now.

The granodiorite is gray to dark gray and generally has a "pepper and salt" appearance. The texture is fine with grain size generally about 1 or 2 millimeters. Some phases have amphibole needles 3 or 4 millimeters long.

The main constituent is zoned plagioclase ( $An_{35-52}$ , generally andesine). Large irregular grains of microperthite, interstitial quartz, and a little micropegmatite are usually present. Amphibole and biotite are the chief mafics. The amphibole is generally in irregular grains and has optical properties near the following:  $\beta=1.680\pm.001$ ,  $\gamma=1.687\pm.001$ ; 2V moderate to large; X=light yellowish-brown, Y=greenish-brown, Z=dark brownish-green,  $Z>Y>X$ ;  $Y=b$ , maximum extinction angle in vertical zone=24°. In places the amphibole is pale green. Biotite is common and has the following optical properties:  $\beta$  and  $\gamma=1.677\pm.001$ ; Y and Z=dark brown, X=light yellowish-brown. A very little pyroxene was seen in thin sections. Among the accessory minerals are irregular grains and long crystals of iron ore, abundant needles of apatite, sphene, and zircon. A mode of this rock is given in Table 1.



*Conway Granite*

By far the most abundant rock of the White Mountain magma series is the Conway granite. It is finer-grained and less pink than the typical building stone quarried at Redstone, New Hampshire, the type locality, but is similar to what is called Conway granite in the Belknap Mountains and to the rock at Green Mountain in Effingham. It appears to be the youngest of the rocks of the White Mountain magma series, with the exception of the dikes and possibly the granite porphyry. The Conway granite underlies a great circular area and is fairly uniform, except for a finer-grained gray phase which has been quarried just north of Gilman Pond and at a few other places. A similar phase is exposed along the road just west of Merrymeeting Lake. This finer rock is considered to be a phase of the Conway granite; it differs only in the finer grain, the gray color, and a greater proportion of plagioclase. The typical Conway granite of this area is characterized by a pinkish cast, which is most apparent at a distance, by small inclusions of dark diorite and granodiorite, and by miarolitic cavities and druse minerals along joint faces. The minerals of the druses are usually the same as those in the granite—crystals of microperthite, plagioclase, quartz, and biotite—but just north of Gilman Pond there are black needles of tourmaline ( $\epsilon = 1.642 \pm .001$ ,  $\omega = 1.666 \pm .001$ ;  $\epsilon$  = faint brown,  $\omega$  = dark gray, slightly bluish) and a little stilbite (Gillson, 1927). Great blocks of this granite are common in the glacial drift, and massive bluffs are common on the southeast sides of the hills.

Occasional small dikes having the appearance of aplite are found in the Conway granite, and microscopic examination reveals that they are almost entirely micropegmatite.

The grains are commonly 1 to 3 millimeters across, but some biotite flakes and amphibole needles attain 10 millimeters. The structure is massive.

Microperthite, the chief constituent, occurs usually in rather large Carlsbad twins. Oligoclase usually shows some zoning and ranges in composition from  $An_{12}$  to  $An_{20}$ , with much of it being about  $An_{16}$ . Small oligoclase crystals are commonly enclosed or partially replaced by microperthite. Quartz is present in fairly large grains and along the contacts of other minerals. It partially replaces the feldspars. Biotite, the most abundant mafic, appears to be replaced along the edges by quartz and the feldspars. Optical properties of biotite have been determined as follows:  $\alpha = 1.625 \pm .002$ ,  $\beta$  and  $\gamma = 1.666 \pm .001$ ; 2V very small; X = light brown, Y and Z = dark brown and in places with a greenish cast. These properties vary from place to place;  $\beta$  and  $\gamma$  have been found as high as  $1.678 \pm .001$  and as low as  $1.653 \pm .001$ . Amphibole is generally present in small amount. The following optical properties are typical of the amphibole:  $\alpha = 1.686 \pm .002$ ,  $\beta = 1.703 \pm .001$ ,  $\gamma = 1.708 \pm .001$ ; 2V moderate; X = light yellowish-brown, Y = greenish-brown, Z = brownish-green,  $Z > Y > X$ ;  $Y = b$ , maximum extinction angle in vertical zone  $28^\circ$ ; dispersion moderate  $v < r$ . Accessories and alterations include iron ore, zircon, apatite, allanite, sphene, epidote (?), chlorite, muscovite, and hematite. Modes of this rock are given in Table 1.

### *Granite Porphyry*

East of the main mass of White Mountain magma series rocks, granite porphyry crops out rather extensively on several hills, but fresh specimens are most readily obtained in the brook near the west margin of the mass. This rock intrudes the schist and probably the diorite-gabbro.

The granite porphyry is light gray where fresh and yellowish or brown where weathered. The grains of the groundmass are mainly less than 1 millimeter across. Phenocrysts of feldspars and quartz constitute a large portion of the rock. Most of them are about 5 millimeters across, but some of the feldspars are as much as 15 millimeters across. Both plagioclase and potash feldspar are present and show twinning.

Microperthite, the main constituent, forms phenocrysts and much of the groundmass. Many of the phenocrysts are twinned according to the Carlsbad law. Oligoclase ( $An_{10-15}$ ) occurs in irregular grains in the groundmass and as phenocrysts. Quartz forms irregular grains in the groundmass and irregular phenocrysts. Biotite is the main mafic mineral and has the following optical properties:  $\beta$  and  $\gamma = 1.660 \pm .001$ ,  $\alpha = 1.620$  (calculated from the birefringence);  $2V$  very small; pleochroism dark brown to light brown. A very few small fragments of bluish amphibole were seen. Accessories include iron ore, apatite, zircon, allanite, and sphene. The mode of this rock is given in Table 1.

### *Dikes*

In almost all the areas of White Mountain magma series there are many dikes of various types, owing, no doubt, to the great amount of differentiation of the magma. Dikes are common in the Merrymeeting Lake area, also, but not so common as at Red Hill (Quinn, 1937, pp. 390-394) or the Belknap Mountains. No study of them was made, but their appearance in the field indicates that they are similar to those at Red Hill and the Belknap Mountains.

### *Structure*

The leucorhyolite may be extrusive. The present mass of it is only a remnant left after the intrusion of the Conway granite. Both the leucorhyolite and the schist mass at the top of Copple Crown Mountain are probably pendants from, or inclusions near, the roof of the large Conway granite intrusion.

The intrusions cut sharply across the older rocks, and affect neither the foliation of the metamorphic rocks nor the contact of the schist and the Winnepesaukee quartz diorite.

The diorite-gabbro, the Conway granite, and the granite porphyry form circular areas, although the diorite-gabbro is somewhat irregular. The border granodiorite has the shape of an incomplete ring-dike, but it may have been intruded in some other form, and its present shape may be due to the later intrusion of the Conway granite, as explained in the description of the border granodiorite.



There seems to be sufficient evidence here to reveal the method of emplacement of the intrusions. The cross-cutting relationship shows that the intrusions did not thrust aside the older rocks, though they may have pushed them up or the older rocks might have sunk. The schist block at the top of Copple Crown Mountain and the masses of older leucorhyolite on the upper slopes of Copple Crown Mountain would be difficult to explain if the older rocks had been pushed up, but seem to fit in well with the subsidence explanation as roof pendants or inclusions a short distance below the roof. Down-sinking is a demonstrated process in New Hampshire and elsewhere, and there is good reason to believe that solid rocks are generally more dense than magmas of about the same composition. Furthermore, the almost circular areas of these intrusions, especially the Conway granite, support the subsidence idea. Similar shapes characterize intrusions in areas where cauldron subsidence has been demonstrated, as, for example, the near-by Ossipee Mountains (Kingsley, 1931), the Belknap Mountains (Modell, 1936), the Percy region of New Hampshire (Chapman, 1935), and Ascutney Mountain, Vermont (Chapman and Chapman, 1940). Cauldron subsidence may produce circular intrusions, ring-dikes, or both, depending upon the amount of subsidence of the central mass and upon the position of the surface of exposure (Chapman, 1935, p. 421; Chapman and Chapman, 1940, pp. 204-205). Piece-meal stoping would probably produce bodies of less regular shapes and would be indicated by more abundant large inclusions.

The evidence seems to justify the conclusion that these intrusions were emplaced by cauldron subsidence.

#### *Correlation with the White Mountain Magma Series Elsewhere*

On previous pages it has been indicated that these rocks are to be correlated with the White Mountain magma series elsewhere, but a statement of the reasons for the correlation was postponed until the descriptions of the rocks had been given. Considerable variety of evidence supports this correlation. (1) The proximity of these rocks to other areas of White Mountain magma series supports this correlation. Proximity is a necessary, but not a sufficient, condition for correlation of this type. (2) Similar rock types and minerals occur. The Conway granite, which is one of the most widespread types of this series, is present. It has the same characteristics, including miarolitic cavities and small dark inclusions. Such inclusions are common in many rocks of the White Mountain magma series. The intrusive breccia of diorite in Conway granite is similar to the intrusive breccia in the Belknap Mountains. Such minerals as the amphiboles and the micropertthite are very similar to those of many other areas of White Mountain magma series. Pegmatites are uncommon here,

which is in contrast to the intrusions of the older magma series in this part of New Hampshire. (3) The age of these rocks may be the same as that of other White Mountain magma series rocks, although at no place is the age of these rocks known within close limits. In common, they cut the rocks of the New Hampshire magma series, are later than the metamorphism of the schist and lime-silicate rock, and are older than the Pleistocene glaciation. Physiographic evidence indicates an age considerably greater than Pleistocene. That, admittedly, may be a rather long time, but, at any rate, there is no known evidence against their common age. (4) Differentiation is marked in these rocks and dikes of several types are common, as is usual for White Mountain magma series, and the course of differentiation is the usual one. (5) The igneous structure is of the cauldron subsidence type, which is common for rocks of this series.

### *Differentiation*

No new evidence concerning the method of magmatic differentiation has been found, but there are several indications that the differentiation was similar to that at other areas of the White Mountain magma series, particularly the Belknap Mountains.

The presence of several different types of rock in this small area seems to indicate considerable magmatic differentiation. There is no indication here of any important differentiation in place, however, and the differentiation must have occurred below the present surface. This is true of most of the near-by areas of White Mountain magma series, with the possible exception of Red Hill where the nepheline-sodalite syenite seems to show differentiation in place (Quinn, 1937, p. 396).

So far as the age relations can be determined, the gabbroic rocks preceded the more granitic rocks. The leucorhyolite is older than the Conway granite and may be older than the diorite-gabbro, and at near-by areas rhyolitic and other lavas commonly preceded the more basic intrusions. That relationship has not been satisfactorily explained.

These similarities indicate that the rocks of the Merrymeeting Lake area probably went through the same type of differentiation as did the rocks of near-by areas of the same series. The final solution of the problem of differentiation will probably come from a complete study of the White Mountain magma series.

### SUMMARY AND CONCLUSIONS

Descriptions are given for the older rocks which include mica schist, lime-silicate rock, and the Winnepesaukee quartz diorite.



Rocks of the White Mountain magma series from gabbro to granite are described. Most of them are intrusive, but leucorhyolite may be extrusive.

The intrusions are considered to have been emplaced by cauldron subsidence, because of the cross-cutting relationship, the circular shape, and the near-by examples of cauldron subsidence.

These rocks are correlated with the White Mountain magma series on the basis of proximity, similarity of rocks and minerals, age, differentiation, and structure.

The similarity of rock types, methods of intrusion, and order of intrusion indicate magmatic differentiation similar to that for other areas of the White Mountain magma series.

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# BRADLEYITE, A NEW MINERAL, SODIUM PHOSPHATE-MAGNESIUM CARBONATE<sup>1</sup>

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with

X-ray Analysis

by

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## ABSTRACT

An anisotropic fine grained mineral, associated with shortite and carbonaceous clay, was found in the drill core of the John Hay Jr. Well No. 1 in Sweetwater County, Wyoming, at a depth of 1342'10". It has been named bradleyite in honor of Dr. W. H. Bradley of the Geological Survey. Chemical analysis shows that the formula is  $\text{Na}_3\text{PO}_4 \cdot \text{MgCO}_3$ . X-ray powder diffraction photographs of bradleyite made with filtered copper K-radiation show that it does not contain  $\text{MgCO}_3$  in the form of magnesite. The spacings and intensities of the lines of the x-ray powder photograph of bradleyite are tabulated to aid in its future identification.

## INTRODUCTION

A second new mineral has been found in the oil shale of the drill core of the John Hay Jr. Well No. 1 from which shortite,<sup>2</sup>  $\text{Na}_2\text{Ca}_2(\text{CO}_3)_3$ , was obtained and recently described. This well, in the Green River formation, is on government land about 20 miles west of the city of Green River, Sweetwater County, Wyoming. Because of the unusual association of minerals found in these shales, the writer visited the area in the summer of 1939 and through the courtesy of the Mountain Fuel Supply Company was able to obtain about 500 feet of the drill core containing the saline minerals in the shale. This is now being examined critically and carefully logged throughout its length.

Bradleyite was found as a layer an inch thick at a depth of 1342'10". The other saline minerals in the drill core so far determined are trona, shortite, pirssonite, gaylussite, bromlite, and northupite. Montmorillonite, quartz, dolomite, and pyrite are also present. The new mineral is named bradleyite in honor of Dr. Wilmot H. Bradley of the Geological Survey, U. S. Department of the Interior, whose many years of productive geologic investigation in this area well merit this recognition.

<sup>1</sup> Published by permission of the Director, Geological Survey, U. S. Department of the Interior, Washington, D. C.

<sup>2</sup> Fahey, J. J., Shortite, a new carbonate of sodium and calcium: *Am. Mineral.*, **24**, 514-518 (1939).



The writer wishes to express his thanks to Dr. George Tunell of the Geophysical Laboratory, Washington, D. C., who contributed the section on x-ray analysis.

#### OCCURRENCE

The one-inch layer of very fine grained bradleyite contains about 30 per cent of much coarser shortite, and 10 per cent of clay (montmorillonite). The clay contains organic matter which yields oil when heated in a closed tube. A thin section shows that the crystals of shortite have been partly replaced by bradleyite. Above the bradleyite, the core consists essentially of shortite and northupite with a little clay; below the bradleyite, it consists of brown clay which contains about 40 per cent of shortite and 20 per cent of northupite. In both parts of the core the northupite is later than the shortite.

#### PHYSICAL PROPERTIES

The bradleyite is extremely fine grained. Hardly any grain, extinguishing as a unit, as seen in thin section under high magnification, is more than 0.002 mm. across. The birefringence is strong. Only the extreme indices of refraction could be measured,  $\alpha$  being about 1.49 and  $\gamma$  about 1.56, hence the birefringence is about 0.07.

The mean index of refraction of the clay is about 1.555, that of the bradleyite mixed with clay is 1.530. Taking into consideration the relative proportions of bradleyite and clay in the mixture (85 and 15 per cent respectively), by computation the mean index of bradleyite is probably close to 1.525.

The light-gray color of the sample is probably due to the admixed darker clay, pure bradleyite being probably white or colorless.

The specific gravity of the sample analyzed, determined with a pycnometer, using toluol, is 2.646. That of the clay, determined in the same way, is 2.141. From these values and the percentage of clay in the bradleyite sample, the specific gravity of pure bradleyite was calculated to be 2.734. By applying the Gladstone Dale equation a good check on the specific gravity was obtained with the figure 2.725.

No value for hardness could be obtained.

#### X-RAY ANALYSIS BY GEORGE TUNELL

X-ray powder diffraction photographs were made of natural bradleyite mixed with 15 per cent of oil shale with use of copper K-radiation filtered through nickel foil, and for comparison, diffraction photographs were made in the same camera, also with use of copper K-radiation filtered through nickel foil, of the oil shale from which the bradleyite had

been removed by solution, and also of magnesite. The next strongest line of the oil shale pattern is not present at all on the films of bradleyite mixed with 15 per cent of oil shale, and the strongest line of the oil shale pattern if present at all merely adds very slightly to a strong line of bradleyite with which it is almost coincident. The remaining lines of the oil shale pattern are not visible on the powder photograph of bradleyite.

The lines of the powder diffraction pattern of bradleyite are listed in Table 1. The intensities were estimated visually on a scale of ten, where

TABLE 1. PLANAR SPACINGS AND RELATIVE INTENSITIES OF THE DIFFRACTION LINES IN THE X-RAY POWDER SPECTRUM OF BRADLEYITE

(Filtered CuK-radiation)		(Filtered CuK-radiation)	
Spacing	Intensity	Spacing	Intensity
8.939Å	3	1.598Å	$\frac{1}{2}$
3.680	5	1.562	3
3.319	10	1.494	4
2.969	2	1.443	3
2.658	10	1.385	4
2.566	8	1.331	2
2.467	$\frac{1}{2}$	1.288	2
2.388	$\frac{1}{2}$	1.251	1
2.313	$\frac{1}{2}$	1.224	$\frac{1}{2}$
2.209	3	1.186	1 (broad)
2.116	4	1.151	2
2.025	$\frac{1}{2}$	1.101	3
1.935	4	1.068	2
1.842	8	1.038	1
1.760	$\frac{1}{2}$	1.011	$\frac{1}{2}$
1.704	$\frac{1}{2}$	0.987	$\frac{1}{2}$
1.658	6		

ten represents the intensity of the strongest line. Several powder diffraction photographs of bradleyite mixed with 15 per cent oil shale were made and one of bradleyite and oil shale mixed with sodium chloride. The spacings of the bradleyite lines were determined by comparison with the sodium chloride lines on the latter film.

The powder photographs of bradleyite and magnesite were compared to establish the fact that bradleyite is not composed of a mixture of magnesite and some other compound; there is no line on the powder photograph of bradleyite corresponding to the strongest line of the magnesite pattern; hence, the presence of any substantial proportion of magnesite in bradleyite is excluded. There is no reason to suppose from the evidence of the x-ray photographs that bradleyite is a mixture.



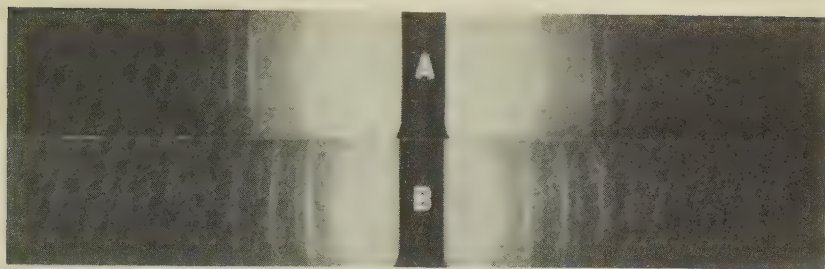


FIG. 1. X-ray powder photographs of (A) bradleyite and (B) magnesite taken with filtered copper K-radiation.

#### CHEMICAL COMPOSITION

Part of the one-inch layer of bradleyite was crushed, care being taken to avoid as much as possible the formation of fines. The crushed material was then sieved and that portion passing 60 mesh and retained on 100 mesh was passed through the Frantz isodynamic magnetic separator by which means most of the shortite was removed. The final sample (about 15 grams) was estimated by microscopic examination to contain less than one per cent of shortite. It was not possible to remove the clay so the sample analyzed consisted of about 85 per cent of bradleyite, 14 per cent of clay, and one per cent of shortite.

Bradleyite is very slowly decomposed by cold water, only a few per cent of sodium carbonate going into solution when allowed to stand over night. Water was determined by loss in both the sample analyzed and in the separated clay, and properly allocated. The bradleyite was dissolved, by treatment for one minute with cold ten per cent hydrochloric acid solution, leaving a residue of clay. The clay was filtered off, air dried, and weighed. The other constituents were obtained in the filtrate.

#### ANALYSIS OF BRADLEYITE

Clay	14.46
MgO	12.91
Na <sub>2</sub> O	31.62
P <sub>2</sub> O <sub>6</sub>	22.03
CO <sub>2</sub>	15.80
Fe <sub>2</sub> O <sub>3</sub>	0.52
Al <sub>2</sub> O <sub>3</sub>	0.24
CaO	0.36
SO <sub>3</sub>	0.46
Cl	0.35
SiO <sub>2</sub>	0.02
H <sub>2</sub> O below 100° C.	0.30
H <sub>2</sub> O above 100° C.	None
K <sub>2</sub> O	None
	<hr/> 99.07

## COMPUTATION OF FORMULA

The CaO (0.36%) found in the analysis was considered to have come from the shortite present and the Na<sub>2</sub>O and CO<sub>2</sub> equivalents were deducted before computing the formula. In the sample no minerals containing chlorine or sulfate were observed. Hence the fractional percentages of these constituents were not applied as corrections in the computations.

	Per cent	Molecular ratios
Na <sub>2</sub> O	31.42	0.507 = 3.04
MgO	12.91	0.323 = 1.93
P <sub>2</sub> O <sub>5</sub>	22.03	0.155 = 0.93
CO <sub>2</sub>	15.38	0.350 = 2.10
Formula: 3Na <sub>2</sub> O · 2MgO · 2CO <sub>2</sub> · P <sub>2</sub> O <sub>5</sub> or Na <sub>3</sub> PO <sub>4</sub> · MgCO <sub>3</sub> or Na <sub>3</sub> MgCO <sub>3</sub> PO <sub>4</sub> .		

In the absence of morphologic evidence the proof that bradleyite is a compound and not a mixture rests chiefly on the chemical and x-ray data. Tunell has shown that there is no magnesite in the sample of bradleyite that was analyzed. The low solubility of bradleyite in water (less than 5 per cent in 20 hours) rules out the possibility that either sodium phosphate or sodium carbonate may be present as separate compounds; furthermore, the simple atomic ratios indicate the existence of a definite compound.

## BISMOCLITE FROM GOLDFIELD, NEVADA\*

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### ABSTRACT

The oxidized bismuth mineral from Goldfield, Nevada, previously described as "bismite," proves on re-examination to be bismoclite,  $\text{BiOCl}$ . The described and illustrated hexagonal crystals, thought to be "bismite," are probably iodyrite.

The oxidized bismuth mineral occurring in several mines of the Goldfield district, Nevada, as pearly scales of brilliant and almost metallic luster, was described as bismite by Ransome and Schaller<sup>1</sup> with the suggestion that its formula might be  $\text{Bi}(\text{OH})_3$  or  $\text{Bi}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ , a formula approximated by an analysis of a gray bismuth ocher from Pala, California.<sup>2</sup> At the suggestion of Dr. Harry Berman, the mineral from Nevada was re-examined in an attempt to harmonize the discrepancies reported in the literature under the name of bismite. As the sample originally analyzed contained nearly 80 per cent of quartz gangue, an attempt was made to concentrate the bismuth mineral by flotation of the gangue in methylene iodide. Although the quantity of gangue was thereby reduced, the sample reanalyzed still contained about 35 per cent of foreign material.

Preliminary tests showed that the mineral contained chlorine, previously missed, and the analysis agrees with that of the recently described bismoclite.<sup>3</sup> The new analysis of the mineral from Nevada (from type specimen previously described, U. S. Nat. Mus. Coll. no 86847) is shown in Table 1.

Spectrographic examination of the analyzed sample by George Steiger showed the presence of Ag, Sn, Cu, Pb, and Sb, and the absence of As, B, Be, Cd, W, and Zn.

Comparative tests made of the silver halide precipitated from a nitric acid solution of the bismoclite from Nevada with the silver halides precipitated from solutions of potassium chloride, bromide, and iodide demonstrate that the halide in the bismoclite is chlorine. These tests are the color (and change of color on exposure to light) of the precipitate and closed tube tests with bisulfate and with galena.

\* Published by permission of the Director, Geological Survey.

<sup>1</sup> Ransome, F. L., The geology and ore deposits of Goldfield, Nevada: *U. S. Geol. Survey, Prof. Paper* **66**, 121-123 (1909); Schaller, W. T., and Ransome, F. L., Bismite: *Am. Jour. Sci.*, 4th ser., **29**, 173-176 (1910), Schaller, W. T., Bismite from Nevada: *U. S. Geol. Survey, Bull.* **490**, 33-36 (1911).

<sup>2</sup> Schaller, W. T., Bismuth ochers from San Diego County, California: *Jour. Am. Chem. Soc.*, **33**, 164 (1911).

<sup>3</sup> Mountain, E. D., Two new bismuth minerals from South Africa (Bismoclite from Steinkopf, Namaqualand, Cape Province): *Mineral. Mag.*, **24**, 59-62 (1935).



TABLE 1. ANALYSIS OF BISMOCLITE

	Nevada		Africa	BiOCl
	Analysis	Same with im- purities deducted and reduced to 100 per cent	Analysis	Calculated
Bi <sub>2</sub> O <sub>3</sub>	57.67	88.53	88.49	89.41
Cl	8.15	12.51	13.00	13.67
H <sub>2</sub> O—	0.13	0.20	0.42	—
H <sub>2</sub> O+	1.03	1.58	0.45	—
Fe <sub>2</sub> O <sub>3</sub>	0.28	—	0.12	—
Insoluble	34.81	—	0.77	—
	102.07	102.82	103.25	103.08
Less O = Cl <sub>2</sub>	1.84	2.82	2.93	3.08
	100.23	100.00	100.32	100.00

It is not known whether the per cent and a half of H<sub>2</sub>O+ in the new analysis indicates a trend towards daubreeite, or whether the H<sub>2</sub>O belongs to the gangue. The quantity of available material is too limited to prepare a sample suitably free from gangue for such a determination. The water determinations were made by loss, using sodium tungstate as a retaining flux.

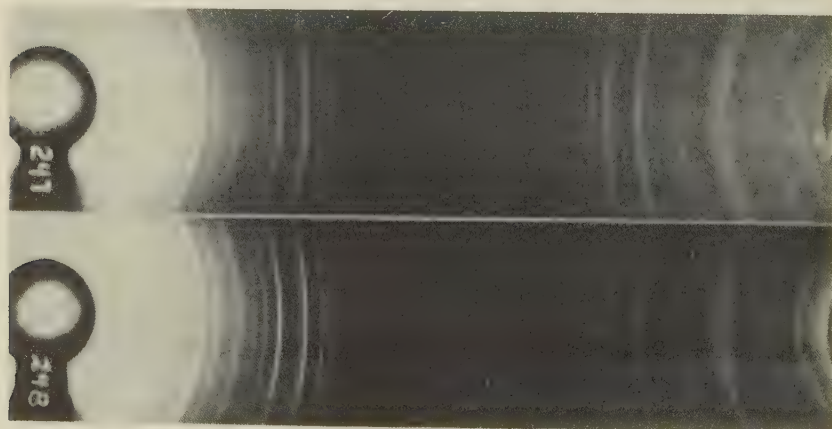


FIG. 1. X-ray powder photographs of artificial BiOCl (247) and of bismoclite from Nevada (248).

X-ray powder photographs, shown in Fig. 1, were made by Dr. W. E. Richmond of the mineral and of artificially prepared crystalline  $\text{BiOCl}$ . This was obtained as described by Bannister.<sup>4</sup> The pictures show the identity of the so-called bismite from Nevada with bismoclite.

Examination under the microscope of the sample analyzed and of crushed fragments from the very small remaining sample shows many very thin rectangular plates, some of which have the corners truncated by lines at  $45^\circ$ . The mineral and synthetic  $\text{BiOCl}$  definitely are tetragonal, as described by Mountain and Bannister. Very rarely one or two minute crystals are observed which are definitely hexagonal, as previously described. On one complete hexagonal crystal the angles, as measured under the microscope, gave the values  $58^\circ$ ,  $61^\circ$ ,  $60^\circ$ ,  $62^\circ$ ,  $61^\circ$ ,  $59^\circ$ . This crystal was found to be optically uniaxial positive, whereas the bismoclite is uniaxial negative. This suggests at once that the hexagonal crystals are a second mineral, intimately associated with the bismoclite.

A consideration of the available information suggests strongly that the hexagonal crystals are iodyrite. They are better developed crystallographically than the plates of bismoclite and so were originally selected for goniometric measurements.

The measurements earlier given on supposed hexagonal crystals of bismite agree well with the angles of iodyrite as shown in the following table, based on  $c=0.8196$ , as given by Dana. The measurements and "indices given for bismite" are taken from the papers by Ransome and Schaller. If these hexagonal crystals are really iodyrite, then the forms  $\{10\bar{1}8\}$ ,  $\{10\bar{1}7\}$ ,  $\{10\bar{1}6\}$ ,  $\{10\bar{1}4\}$ ,  $\{10\bar{1}3\}$  are new for iodyrite. The agreement between the measured and calculated angles is so close that this interpretation is probably correct.

Ransome<sup>5</sup> did not report iodyrite from Goldfield but noted the presence of the silver minerals cerargyrite, petzite, polybasite, and proustite. Iodyrite, however, occurs at Tonopah, about 25 miles north of Goldfield. In their description of iodyrite from Tonopah, Kraus and Cook<sup>6</sup> examined "several thousand isolated crystals" and as type 3 describe crystals of a "tabular habit." Tabular and platy crystals of iodyrite have also been observed by others. Dana<sup>7</sup> describes it, in part, as occurring in "thin plates with a lamellar structure." Hintze<sup>8</sup> lists the habits of iodyrite as prismatic, pyramidal, or platy, and the natural occur-

<sup>4</sup> Bannister, F. A., The crystal-structure of the bismuth oxyhalides: *Mineral. Mag.*, **24**, 49 (1935).      <sup>5</sup> Ransome, *op. cit.*, p. 108.

<sup>6</sup> Kraus, E. H., and Cook, C. W., Iodyrite from Tonopah, Nevada, and Broken Hill, New South Wales: *Am. Jour. Sci.*, 4th ser., **27**, 213 (1909).

<sup>7</sup> Dana, E. S., *System of Mineralogy*, 6th ed., p. 160 (1892).

<sup>8</sup> Hintze, Carl, *Handbuch der Mineralogie*, Band 1, Abth. 2, p. 2309 (1915).

COMPARISON OF ANGLES MEASURED ON HEXAGONAL CRYSTALS OF SUPPOSED "BISMITE"  
WITH THOSE OF IODYRITE

Indices given for bismite	Correct indices for iodyrite	$\rho$	
		Measured	Iodyrite
0001	0001	—	—
10 $\bar{1}$ 6	10 $\bar{1}$ 8	6°37' 6 41	6°45'
10 $\bar{1}$ 5	10 $\bar{1}$ 7	7 33 7 36	7 42
10 $\bar{1}$ 4	10 $\bar{1}$ 6	9 31 9 31 8-9	9 03
10 $\bar{1}$ 3	10 $\bar{1}$ 4	12 11 13 18 12 26 12-14	13 19
2025 10 $\bar{1}$ 2	10 $\bar{1}$ 3	15 16-20	17 31
01 $\bar{1}$ 1	3034	35 35 32½	35 22
2021	3032	54 54	54 50

rences as commonly laminated and as thin flexible plates. Crystals from Chile are described as in pearly hexagonal plates ("Blättchen") and from New Mexico, rarely as hexagonal plates ("Tafelchen"). Spencer<sup>9</sup> also mentions "Films or thin layers" of iodyrite and states that "in freshly opened cavities the crystals [of iodyrite] are perfectly colorless and transparent . . .," like those from Nevada.

Schnaebelé<sup>10</sup> likewise describes and illustrates very platy ("très aplatie") crystals of iodyrite (his Fig. 6, p. 69) from France.

No more of the hexagonal crystals could be found on the very limited material available so that their identification with iodyrite could not be substantiated.

<sup>9</sup> Spencer, L. J., Marshite, miersite and iodyrite from Broken Hill, New South Wales: *Mineral. Mag.*, **13**, 44 (1903).

<sup>10</sup> Schnaebelé, E., L'iodargyrite des Montmins, près Echassières (Allier): *Bull. soc. fr. Minéralogie*, **45**, 68-69 (1922).



## EL BURRO, COAHUILA, MEXICO, METEORITE

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### ABSTRACT

A new meteorite from northern Coahuila, Mexico, is described and its chemical composition compared to an iron-nickel equilibrium diagram. Reasons are given why El Burro is classified as a coarse octahedrite and also why brecciated hexahedrites are likely to be very coarse octahedrites.

The El Burro meteorite was found in northern Coahuila, Mexico, in April of 1939, but it is not a new fall. The place of discovery is best located by giving the latitude  $29^{\circ}20'N$ . and longitude  $101^{\circ}50'W$ . as the area has few settlements and hence it is impossible to assign a geographical name of any nearby town. According to our informant this meteorite was found close to some hills known as El Burro, and hence the reason why this name was selected.

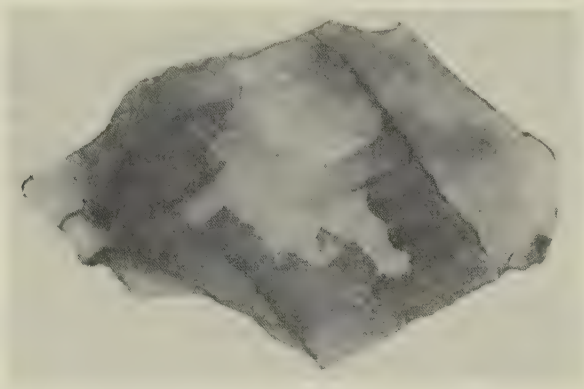


FIG. 1. Polished cross-section of El Burro, Coahuila, Mexico, meteorite. The kamacite area at the left is 8.5 cm. long and 3 cm. wide when measured in its greatest dimensions, and is separated from the adjoining area by a continuous film of brown iron oxide.

When received at the National Museum the 79 pound meteorite showed a jagged surface on one portion of it suggesting a rather recent break, and the remaining area is weathered. None of the flight features was preserved on this meteorite.

Sections of this iron were made in our laboratory and all show large and irregular areas of kamacite. All the kamacite areas appear to be separated by thin zones of a brown material assumed to be secondary iron oxide. Some schreibersite is present in these oxide veins and in a few places the kamacite areas are separated by a filling of schreibersite.

Taenite, usually found between kamacite areas, is almost non-existent; in fact, a careful search had to be made of the kamacite individuals which

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were broken off from the main mass before any taenite was found. A few thin, scale-like pieces were found but it is definitely not an abundant constituent.

The absence of any easily detectable quantities of taenite, on the one hand, and the finding of large, irregular areas of kamacite would suggest that perhaps this meteorite was a brecciated hexahedrite. This is a term which has been used many times to describe similar structures, but to this author it never seemed an entirely satisfactory usage. Having been interested in the composition of hexahedrites, this meteorite afforded an excellent opportunity to determine if the nickel content would agree with the iron-nickel diagram of Owens and Sulley,<sup>1</sup> which apparently holds for hexahedrites. Since El Burro has a very coarse kamacite structure, and also contains such a very small quantity of taenite, it is important to know if its nickel content would lie in the  $\alpha$ -iron or  $\alpha+\gamma$  iron field of Owens and Sulley's diagram.

To classify a meteorite as belonging to the octahedral group, it is necessary not only for the kamacite to have an octahedral arrangement, but also some taenite should be present. That is, it should consist of two phases. If El Burro is a hexahedrite, or single phase meteorite, with a brecciated structure then its nickel content should lie in the range of composition of the  $\alpha$ -iron.

ANALYSIS OF EL BURRO  
E. P. Henderson, *analyst*

Fe	93.10%
Ni	6.02
Co	.34
P	.32
S	trace
Insol.	.01
Total	99.79%

The El Burro meteorite contains 6.02% nickel which is just within the  $\alpha+\gamma$  iron field as shown by Owen and Sulley.<sup>2</sup> It is also definitely above the average nickel content for hexahedrites which was found to be between 5.52% and 5.6%.<sup>3</sup>

Therefore, the El Burro is classified as a very coarse octahedrite. A good probability exists that some of the so-called brecciated hexahedrites should be more properly classified in this group of octahedrites rather than as brecciated hexahedrites.

<sup>1</sup> Owens, E. A., and Sulley, A. H., Equilibrium diagram of iron-nickel alloys: *Phil. Mag. and Jour. Sci.*, **27**, no. 184, p. 633, May (1939).

<sup>2</sup> Owen, E. A., and Sulley, A. H., *Idem*.

<sup>3</sup> Henderson, E. P., Chilean hexahedrites and the composition of all hexahedrites: *Am. Mineral.*, **26**, 546-550 (1941).

# PARAMELACONITE: A TETRAGONAL OXIDE OF COPPER

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## ABSTRACT

Paramelaconite is an oxide containing both cuprous and cupric copper. The ideal composition is  $\text{CuO}$ . The actual constitution is based on an oxygen-defect structure in which the loss of negative valence accompanying the omission of oxygen atoms is compensated by a change in positive valence of some cupric ions to cuprous. The observed composition may be expressed as  $(\text{Cu}^{2}_{1-2x}, \text{Cu}^{1}_{2x})\text{O}_{1-x}$  where  $x=0.116$ .

Data derived from the morphology, etch-figures, and a Weissenberg x-ray study fix the crystal system as tetragonal and the crystal class as ditetragonal-dipyramidal. The mineral occurs as lustrous black crystals up to 3 cm. in size. The observed forms are  $\{001\}$ ,  $\{101\}$  and  $\{100\}$ , with  $a:c=1:1.6709$ . The structure cell is body-centered tetragonal with  $a_0=5.83$ ,  $c_0=9.88$ ; and  $a_0:c_0=1:1.695$ . The observed cell contents are  $\text{Cu}^{2}_{16-2x}, \text{Cu}^{1}_{2x}\text{O}_{16-x}$  where  $x=1.85$ . The space group is  $I4/amd$ . A pronounced pseudo-cell is present, having  $a_0=2.915$ ,  $c_0=4.94$ , and is body-centered with the space group  $I4/mmm$ . The pseudo-cell probably defines the essential characters of the structure and the doubled cell may mark a superstructure based on an ordering of the cuprous ions or of the oxygen-defect positions.

The physical properties of paramelaconite are: fracture, flat conchoidal; hardness, 4½; specific gravity, 6.04; luster, brilliant metallic-adamantine; color, black to purplish black; streak, brownish black; opaque. In polished section, it is white with a pinkish brown tint; weakly pleochroic and strongly anisotropic. The mineral is etched by  $\text{FeCl}_3$ ,  $\text{KCN}$ ,  $\text{HCl}$  and  $\text{HNO}_3$  but not by  $\text{KOH}$ . On heating, paramelaconite breaks down at a slow but measurable rate below  $190^\circ \text{C.}$ , and more rapidly with increasing temperature, to a mixture of

\* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 245.



tenorite and cuprite. The crystallites of tenorite and cuprite are randomly oriented. Paramelaconite is easily soluble in cold dilute  $\text{NH}_4\text{Cl}$  or  $\text{NH}_4\text{OH}$  solution, and fragments become coated by a mixture of metallic copper and cupric oxide when placed in extremely dilute mineral acids. Spectrographic examination revealed: Fe ( $>1\%$ ); Al, Mn, Si, Mg, Ba ( $<0.1\%$ ); Ca, Pb, Zn, Zr, Mo, Ti ( $<0.01\%$ ); Sn, V ( $<0.001\%$ ).

Paramelaconite was found at the Copper Queen mine, Bisbee, Arizona, as a secondary mineral in the following association and sequence: (matrix=goethite, native copper, cuprite)→goethite→tenorite→paramelaconite (and minor cuprite)→connellite→malachite. The mineral alters to tenorite. Twelve specimens of black earthy or pitch-like cupric oxide, including material labelled melanochalcite, melaconite, copper-pitch and paramelaconite, proved on *x*-ray study to be either delafossite (for which a new locality, at Eureka, Nevada, is noted) or tenorite.

### INTRODUCTION

Paramelaconite was originally described by Koenig in 1891 as a tetragonal modification of cupric oxide, dimorphous with tenorite. Neither the

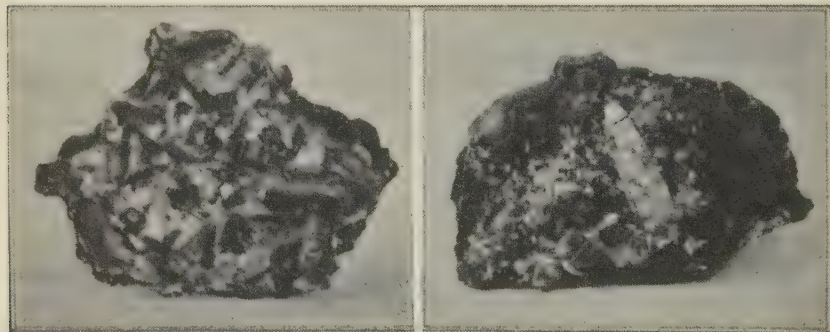


FIG. 1. The two known specimens of paramelaconite. Copper Queen mine, Bisbee, Arizona. Amer. Mus. Nat. Hist., spec. nos. 4629 and 4630. A large needle-like crystal of connellite may be seen on one specimen (left). About one-third natural size.

system of crystallization nor the composition of the mineral was established with any certainty, however, and the substance never received recognition as a valid species. Only two specimens of paramelaconite are known. These were obtained by Dr. A. E. Foote, about 1890, at the Copper Queen mine, Bisbee, Arizona, and were sold by him to the well known mineral collector Clarence S. Bement for fifty dollars apiece. Koenig examined the specimens with the permission of Bement. The Bement collection, at the time considered to be the finest private mineral collection in the United States, later passed into the possession of the American Museum of Natural History, where the two specimens are now preserved. The paramelaconite is magnificently crystallized, and is associated with a deep blue prismatic mineral which was described by Koenig as a new basic chloride of copper, under the name footeite. This mineral

was later shown to be connellite in crystals of unusual size. Photographs of the two specimens of paramelaconite are shown in Fig. 1. The writer is grateful to Dr. Fred. H. Pough, Curator, and Mr. Herbert P. Whitlock, of the American Museum for permission to remove sufficient material from the specimens for a crystallographic and chemical study of this quite unusual mineral.

#### CRYSTALLOGRAPHY

*Morphology.* The paramelaconite occurs as stout prismatic crystals up to 3 cm. in length. The crystals are tetragonal in development, with the forms  $c\{001\}$ ,  $d\{101\}$ , and  $a\{100\}$ , as referred to the simplest structural

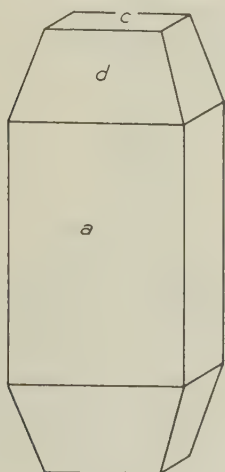


FIG. 2. Idealized crystal.

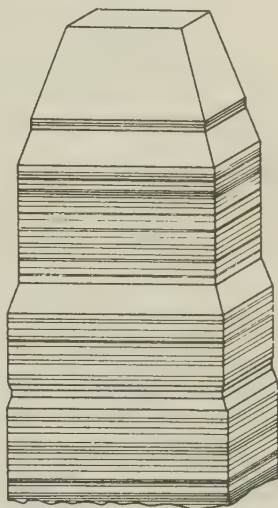


FIG. 3. Striated singly terminated crystal.

cell. An idealized crystal is shown in Fig. 2. The prism surfaces are closely striated and in part deeply grooved due to oscillatory combination with  $\{101\}$ , as represented in Fig. 3. The several faces of  $\{101\}$  and  $\{001\}$  usually are unequally developed. The crystals are attached to the matrix by one end of the vertical axis. Only one doubly terminated individual was observed. This crystal was similarly developed at both ends, with  $\{001\}$  and  $\{101\}$ . The lower half of  $\{101\}$  also occurs on singly terminated crystals as line faces in the grooves and striae on  $\{100\}$ . No difference in general physical appearance was detected between the several upper faces of  $\{101\}$ , or between the upper and lower faces of  $\{101\}$  and  $\{001\}$ .

Koenig obtained  $\{001\} \wedge \{101\} = 58^\circ 50'$ , for which the  $a:c$  ratio was erroneously calculated as 1:1.6643. The correct value is 1:1.6534. Although the crystals appear quite perfect on casual examination, the faces often give multiple images on the reflecting goniometer, due to vicinal

development. A coarse lineage structure is commonly present. The six crystals measured by the writer gave  $\rho$  values for  $\{101\}$  ranging between  $58^{\circ}44'$  and  $59^{\circ}30'$ . The average of the best values was  $59^{\circ}6'$ , for which  $a:c=1:1.6709$ . The ratio of the structural cell is  $a_0:c_0=1:1.695$  for which the calculated  $\rho$  angle of  $\{101\}$  is  $59^{\circ}28'$ . An angle table, based on the elements of the structural cell is given in Table 1. The morphological development is of little aid in fixing the crystal class. Four classes are possible, if it is assumed that the lower and upper planes are geometrically and structurally identical. These are  $4/m\ 2/m\ 2/m$ ,  $4\ 2\ 2$ ,  $\bar{4}\ 2\ m$  and  $4/m$  (see Table 3).

TABLE 1. ANGLE-TABLE FOR PARAMELACONITE

Tetragonal; ditetragonal-dipyramidal— $4/m\ 2/m\ 2/m$ $a:c=1:1.695$ ; $p_0:r_0=1.695:1$				
Forms	$\phi$	$\rho$	A	M
$c\ 001$	—	—	$90^{\circ}00'$	$90^{\circ}00'$
$a\ 010$	0 00	$90^{\circ}00'$	90 00	45 00
$d\ 011$	0 00	59 28	90 00	52 29

*Etch-Figure Symmetry.* Satisfactory etch figures were obtained only after lengthy experimentation. The best results were obtained from a solution about 0.001N  $H_2SO_4$  and 0.3N  $NH_4Cl$ . Etch pits appeared on the crystals after standing in the solution for a few hours. No change in the shape of the pits took place after standing for several days. The shape and orientation of the etch pits and etch hillocks is shown in Fig. 4. The pits on  $\{001\}$  were large, deep four-sided pyramidal depressions with rounded and terraced sides. The base of the figures had a square but somewhat irregular or rounded outline oriented at  $45^{\circ}$  to  $[100]$ . Etch hillocks were obtained on  $\{101\}$ . These were tooth-shaped with the sharp end pointing upward. The hillocks on all four upper faces of  $\{101\}$  were identical. Minute canoe-shaped pits were formed on  $\{100\}$ . The pits were identical in shape and orientation on all four faces of this form. The hillocks on  $\{101\}$  and the pits on  $\{100\}$  were sensibly symmetrical about a line representing the trace on these forms of vertical axial planes. The observed etch effects are consistent with the existence of a vertical four-fold symmetry axis, together with vertical axial and diagonal planes of symmetry and a horizontal plane of symmetry. Horizontal axial and diagonal two-fold axes of symmetry, and a center of symmetry are required by these operations. The crystal class is thus uniquely fixed by the etch symmetry as ditetragonal-dipyramidal ( $4/m\ 2/m\ 2/m$ ).

The velocity of chemical attack is markedly greater along  $[001]$  than perpendicular thereto. The  $\{001\}$  face on a crystal left in the etching solu-



tion for a period of days was completely hollowed out to a depth of about 0.3 mm. leaving the lateral  $\{101\}$  faces standing up as thin walls. The  $\{100\}$  faces at the same time were only pitted locally and for the most part still maintained their original smoothness and luster. The pronounced elongation of the pits on  $\{100\}$  also indicates the greater rate of

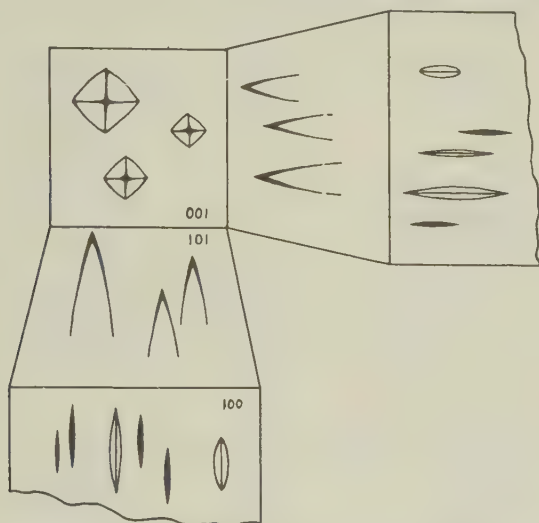


FIG. 4. Etch figures and hillocks on  $\{001\}$ ,  $\{101\}$  and  $\{100\}$  of paramelaconite. Produced in 8 hours by  $\text{NH}_4\text{Cl} + \text{H}_2\text{SO}_4$  solution. The absolute and relative sizes of the figures are greatly exaggerated.

attack along  $\{001\}$ . Similar shell-like solution forms have been obtained by the action of  $\text{H}_2\text{SO}_4$  on  $\{001\}$  of apophyllite crystals.

#### X-RAY STRUCTURAL CELL

A Weissenberg  $x$ -ray study was made of small cut sections and crystals. Cu radiation was employed. Rotation photographs were taken about  $[001]$ ,  $[100]$  and  $[110]$ , together with 0- 1- and 2-layer-lines about  $[100]$ , 0-, 1-, 2-, 3- and 4-layers about  $[001]$ , and a 0-layer about  $[110]$ . The  $n$ -layers were filtered with Ni. The rotation photographs about the vertical and horizontal axes exhibited a very pronounced pseudo-cell of one-half the dimensions of the true cell. It was necessary to take long exposures (40 to 60 KWH at 12 ma. and 55 KV) in order to record the odd-layer lines.

*Centro-Symmetry of the Weissenberg Films.* The 0-layer and  $n$ -layer Weissenberg films taken about  $[001]$  revealed a four-fold axis of symmetry, with planes of symmetry at  $45^\circ$ . The 0-layer and  $n$ -layer films about  $[100]$

and the 0-layer film about [110] revealed a two-fold axis of symmetry, with planes of symmetry at  $90^\circ$ . Paramelaconite is, therefore, tetragonal, and the apparent point symmetry is  $4/m\ 2/m\ 2/m$ . The actual point symmetry of the mineral may be either  $4/m\ 2/m\ 2/m$ , or that of any other crystal class the symmetry of which, by introduction of a center, can be raised to  $4/m\ 2/m\ 2/m$ . These crystal classes are indicated in Table 3.

TABLE 2. CATALOGUE OF OBSERVED X-RAY REFLECTIONS

[001] axis		[100] axis	
0-layer	$\begin{cases} h00 \text{ when } h \text{ is even} \\ h\bar{h}0 \text{ when } h \text{ and } k \text{ are even} \\ h\bar{h}0 \text{ when } h \text{ is even} \end{cases}$	0-layer	$\begin{cases} 00l \text{ when } l=4n \\ h00 \text{ when } h \text{ is even} \\ h0l \text{ when } h+l \text{ is even} \end{cases}$
1-layer	$\begin{cases} h0l \text{ when } h+l \text{ is even} \\ hhl \text{ all absent} \\ hkl \text{ when sum is even} \end{cases}$	1-layer	$\begin{cases} h0l \text{ when } h+l \text{ is even} \\ h\bar{h}0 \text{ all absent} \\ h\bar{h}0 \text{ all absent} \\ hkl \text{ when sum is even} \end{cases}$
2-layer	$\begin{cases} h0l \text{ when } h+l \text{ is even} \\ hhl \text{ all absent} \\ hkl \text{ when } h, k \text{ and } l \text{ are even} \end{cases}$	2-layer	$\begin{cases} h0l \text{ when } h+l \text{ is even} \\ h\bar{h}0 \text{ when } h+k \text{ is even} \\ h\bar{h}0 \text{ when } h \text{ is even} \\ hkl \text{ when sum is even} \end{cases}$
3-layer	$\begin{cases} h0l \text{ when } h+l \text{ is even} \\ hhl \text{ all absent} \\ hkl \text{ when sum is even} \end{cases}$	[110] axis	
4-layer	$\begin{cases} h0l \text{ when } h+l \text{ is even} \\ hhl \text{ when } h \text{ is even} \\ hkl \text{ when } h, k \text{ and } l \text{ are even} \end{cases}$		
		0-layer	$\begin{cases} h\bar{h}0 \text{ when } h=2n \\ 00l \text{ when } l=4n \\ hhl \text{ with sum}=4n \end{cases}$

*Space-Lattice Type and Space Group.* The observed x-ray diffraction effects on the Weissenberg films taken about [001], [100] and [110] are given in Table 2. These data require the space-lattice type to be body-centered. The systematic omissions indicate the presence of an axial glide along [100] in the horizontal plane {001}, and of a diagonal glide in the vertical plane {110}. The space group is uniquely fixed by these operations as  $D_{4h}^{19} = I4/amd$ . This finding confirms the crystal class as ditetragonal-dipyramidal. The evidence bearing on the symmetry of paramelaconite is summarized in Table 3. Additional, apparently systematic, omissions are also present in the 2- and 4-layer Weissenberg photographs taken about [001]. These are without significance for purposes of space group determination, and presumably are due to special properties of the structure, as indicated beyond.

TABLE 3. SYMMETRY OF PARAMELACONITE

Crystal class	Morpho- logical symmetry	Etch symmetry	Weissen- berg film symmetry	Space group symmetry
Ditetragonal-dipyramidal = $4/m\ 2/m\ 2/m$	*	*	*	$I4/amd$
Tetragonal-trapezohedral = $4\ 2\ 2$	*		*	
Ditetragonal-pyramidal = $4\ m\ m$			*	
Tetragonal-scalenohedral = $\bar{4}\ 2\ m$	*		*	
Tetragonal-dipyramidal = $4/m$	*			
Tetragonal-pyramidal = $4$				
Tetragonal-disphenoidal = $\bar{4}$				

*Pseudo-Cell and Structural Relations.* The rotation photographs indicate a marked pseudo-cell with both  $a_0$  and  $c_0$  halved. The intensity of the reflections on the even-layer Weissenberg photographs about both [001] and [100] is for the most part either very strong or weak. A catalogue of the strong reflections is given in Table 4.

TABLE 4. CATALOGUE OF OBSERVED (STRONG) REFLECTIONS IN THE PSEUDO-CELL

[001] axis	[100] axis
0-layer $\left\{ \begin{array}{l} h00 \text{ when } h \text{ is even} \\ (=0\text{-layer of } h00 \text{ when } h+k \text{ is even} \\ \text{true cell}) \quad h00 \text{ all present} \end{array} \right.$	0-layer $\left\{ \begin{array}{l} 00l \text{ when } l=2n \\ (=0\text{-layer of } 000 \text{ when } h \text{ is even} \\ \text{true cell}) \quad h0l \text{ when } h+l \text{ is even} \end{array} \right.$
1-layer $\left\{ \begin{array}{l} h0l \text{ when } h+l \text{ is even} \\ (=2\text{-layer of } hhl \text{ all absent} \\ \text{true cell}) \quad hkl \text{ when } h+k+l \text{ is even} \end{array} \right.$	1-layer $\left\{ \begin{array}{l} h0l \text{ when } h+l \text{ is even} \\ (=2\text{-layer of } h00 \text{ when } h+k \text{ is even} \\ \text{true cell}) \quad hhl \text{ when sum is even} \\ \quad hkl \text{ when sum is even} \end{array} \right.$
2-layer $\left\{ \begin{array}{l} h0l \text{ when } h+l \text{ is even} \\ (=4\text{-layer of } hkl \text{ when } h+k \text{ is even} \\ \text{true cell}) \quad hhl \text{ all present} \end{array} \right.$	

These data indicate that the pseudo-cell is based on a body-centered lattice and is without special symmetry operations. Accordingly, the space group is  $I4/mmm$ . The pseudo-cell probably represents the essential structural make-up of the substance, and the true cell, as described above, may then define a super-structure originating in an ordering of the cuprous ions or of the oxygen-defect positions, as described beyond. Neither the true cell nor the pseudo-cell appears to stand in a close dimensional relation to either cuprite or tenorite. A comparison with some other compounds of the AX type is given in Table 5. Structurally, paramelaconite



probably is based on a square coordinated grouping of oxygen atoms about a central copper atom, analogous to the structure of cooperite, PtS. Such a structure would present analogies to the structure of the monoclinic cupric oxide, tenorite, analyzed by Tunell, Posnjak and Ksanda (1935), in which essentially square coordinated groups of O atoms about Cu atoms are unsymmetrically distorted.

TABLE 5. COMPARISON OF SOME COMPOUNDS OF THE AX TYPE

	Space group	Cell contents	$a_0$	$c_0$	
Paramelaconite (true cell)	$I4/amd$	"Cu <sub>16</sub> O <sub>16</sub> "	5.83	9.88	
Paramelaconite (pseudo-cell)	$I4/mmm$	"Cu <sub>2</sub> O <sub>2</sub> "	2.915	4.94	
PbO (red or $\alpha$ -PbO)	$P4/nmm?$	Pb <sub>2</sub> O <sub>2</sub>	3.99	5.01	
PdO	$P4/nmm?$	Pd <sub>2</sub> O <sub>2</sub>	3.00	5.20	
SnO ( $\alpha$ -SnO)	$P4/nmm?$	Sn <sub>2</sub> O <sub>2</sub>	3.80	4.81	
Cooperite (Pts)	$P4/mmc$	Pt <sub>2</sub> S <sub>2</sub>	3.47	6.10	
Tenorite (CuO)	$C2/c$	Cu <sub>4</sub> O <sub>4</sub>	4.653	5.108	$b_0=3.410$ $\beta=99^\circ29'$
Cuprite (Cu <sub>2</sub> O)	$Pn3m$	Cu <sub>4</sub> O <sub>2</sub>	4.26		

*Cell Dimensions. Powder Diffraction Data.* The edge-lengths of the unit cell as calculated from high order axial reflections on the 0-layer Weissenberg photographs about [001] and [100] are

$$a_0=5.83. c_0=9.88. a_0:c_0=1:1.695.$$

The values calculated from the rotation photographs were  $a_0=5.81$ ,  $c_0=9.87$ , [110] period = 8.14. The powder diffraction data are summarized in Table 6. The powder photograph of paramelaconite is shown in comparison with those of tenorite and cuprite in Fig. 5.

TABLE 6. X-RAY POWDER DIFFRACTION DATA FOR PARAMELACONITE  
Cu radiation. Camera radius = 57.26 mm. (uncorr.)

No.	d	I	Index	No.	d	I	Index
1.	4.027	vw	110	12.	1.233	w	008
2.	3.115	vw	112	13.	1.056	w	228
3.	2.888	w	200	14.	1.025	vw	440
4.	2.490	vs (1)	202	15.	1.017	w	426
5.	2.464	w	004	16.	0.949	w	600
6.	2.050	m	220	17.	0.939	w	444
7.	1.874	vw	204	18.	0.935	w	408
8.	1.575	s (2)	224	19.	0.916	vw	620
9.	1.449	m	400	20.	( $\alpha_1\alpha_2$ ) 0.859	w	624
10.	1.430	m	206	21.	( $\alpha_1\alpha_2$ ) 0.832	w	606
11.	1.251	s (3)	404	22.	( $\alpha_1\alpha_2$ ) 0.821	vw	00.12

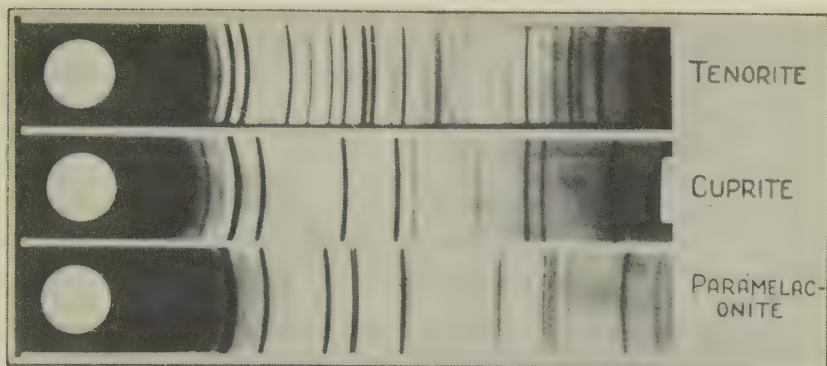


FIG. 5. X-ray powder photographs of tenorite, cuprite and paramelaconite. Cu radiation. Some faint lines do not show in the reproduction of the patterns, and the relative intensity of the stronger lines is not accurately represented.

#### PHYSICAL PROPERTIES

Cleavage is lacking. The fracture is flat conchoidal. The mineral is brittle. It is scratched with difficulty by apatite and scratches fluorite (contrary to the statement of Koenig that the hardness on {001} is equal to that of apatite) so that the hardness is  $4\frac{1}{2}$ . The specific gravity is 6.04. This value represents three identical determinations made on separate grains on the Berman microbalance. The value 5.833 for the specific gravity given by Koenig is in error and probably was obtained on a sample mixed with massive tenorite. The luster of paramelaconite is brilliant metallic-adamantine. The color on fracture surfaces is pitch-black. The color on the natural crystal faces is black with a faint purple tone of color. The streak is brownish-black. It is opaque.

In polished section, the mineral is white with a faint pinkish-brown tint of color. The color resembles that of tenorite but is much whiter. The mineral is weakly pleochroic in white to pinkish-brown, and is strongly anisotropic. Internal reflections were not observed in strong oblique illumination. The substance is etched by  $\text{FeCl}_3$ , KCN, HCl and  $\text{HNO}_3$ , but is almost or entirely negative to KOH. It is strongly tarnished by HCl or  $\text{HNO}_3$  fumes. The above observations were made on sections approximately parallel to [001]. No evidence of twinning or of zonal growth was observed, and the mineral appeared to be entirely homogeneous.

#### CHEMISTRY

*Qualitative Reactions.* Splinters of paramelaconite are rounded at the edges in a strong oxidizing flame. The mineral melts easily and yields metallic copper in the reducing flame. The powder is readily soluble in cold

dilute mineral acids. Fragments are attacked by extremely dilute HCl (a few drops of acid in 50 cc. of water) with the formation of a surface coating of cupric oxide and cuprous chloride. Extremely dilute  $\text{HNO}_3$  or  $\text{H}_2\text{SO}_4$  causes the formation of a loose flaky coating of metallic copper and cupric oxide. The action of the oxidizing agent  $\text{HNO}_3$  in forming metallic copper from cuprous oxide is well known (see Mellor (1923)). The powder is easily soluble without the formation of metallic copper or cupric oxide in cold dilute  $\text{NH}_4\text{Cl}$  or  $\text{NH}_4\text{OH}$  solution. The color of these solutions is blue. Fragments are not appreciably attacked over a period of hours in cold dilute acetic acid.

*Homogeneity. Analyses. Spectrographic Data.* Koenig (1891) stated that inclusions of cuprite were present in the sample analyzed by him. He found (column 1, Table 7) that the mineral was an oxide of copper, with an excess summation of 1.32 per cent when the total copper, determined as  $\text{Cu}_2\text{S}$ , was expressed as  $\text{CuO}$ . The excess was taken to represent oxygen and was calculated as  $\text{Cu}_2\text{O}$ , to the amount of 11.70 per cent. The  $\text{Cu}_2\text{O}$  was then ascribed to the admixed cuprite, and the true composition of the mineral was considered to be  $\text{CuO}$ , like tenorite.

TABLE 7. ANALYSES OF PARAMELACONITE

	1.	2.	3.	4.	5.
Cu			[81.68]	81.80	81.95
O			[18.32]	[18.20]	18.05
$\text{Cu}_2\text{O}$	11.70	19.45	19.97	[21.38]	[23.07]
$\text{CuO}$	87.66	77.94	80.03	[78.62]	[76.93]
$\text{Fe}_2\text{O}_3$	0.64	2.70		0.00	
Total	100.00	100.09	100.00	[100.00]	100.00

1. Analysis by Koenig (1891). Made on 0.2031 gram sample.  $\text{Cu}_2\text{O}$  and  $\text{CuO}$  calculated from excess summation (= 101.32 per cent) of total Cu taken as  $\text{CuO}$  and determined as  $\text{Cu}_2\text{S}$ .

2. Analysis by F. A. Gonyer (January, 1940) on 0.5 gram sample.  $\text{Cu}_2\text{O}$  and  $\text{CuO}$  determined directly by the  $\text{KNa}$  tartrate method.

3. Analysis 2 recalculated to 100 per cent after deduction of  $\text{Fe}_2\text{O}_3$ . Total Cu and O calculated from  $\text{Cu}_2\text{O}$  and  $\text{CuO}$ .

4. Analysis by F. A. Gonyer (March, 1941) on 0.4 gram sample. Total Cu determined directly by electrolytic method.  $\text{Cu}_2\text{O}$  and  $\text{CuO}$  calculated from excess summation (102.39 per cent) of the total Cu taken as  $\text{CuO}$ .

5. Calculated composition for  $\text{Cu}_6\text{Cu}_2\text{O}_7$ .

Koenig's interpretation of the composition is in error, because pure grains of the mineral give strong qualitative tests for cuprous copper. Two samples were prepared for new analyses. Special care was taken to ensure the entire homogeneity of the samples. For the first sample several



single crystals were removed from the specimen and were broken down to a coarse powder. It was observed that the portions of the crystals at their attached ends locally had a dull and coal-like appearance, with a rather uneven fracture. Open lineage cracks in these portions were filled by a soft black material which proved on *x*-ray powder examination to be tenorite. The remainder of each crystal afforded lustrous grains with a flat conchoidal fracture. The sample, when handpicked for impurities, was free from transparent material under the microscope and an *x*-ray powder photograph showed no evidence of admixture. An analysis of this sample was undertaken by Mr. F. A. Gonyer and the results are reported in column 2 of Table 7. The cuprous and cupric copper were separated by precipitation from a Rochelle-salt solution, and the  $\text{Cu}_2\text{O}$  and  $\text{CuO}$  in the filtrate and precipitate were determined by electrolytic determination of the copper. The surprisingly large amount of  $\text{Fe}_2\text{O}_3$  reported undoubtedly represents admixed finely divided iron oxide, in light of the observations of Koenig and of the further analysis reported beyond.

After the completion of the foregoing analysis, a sample was prepared entirely from the lustrous, flat conchoidal material from the apical portion of a single crystal. An *x*-ray powder photograph of the sample showed no evidence of admixture. The results of this analysis are tabulated in column 4 of Table 7, and are considered to represent very accurately the composition of the mineral. The total copper was determined electrolytically, and the relative amounts of the  $\text{Cu}_2\text{O}$  and  $\text{CuO}$  were calculated from the excess summation taken as oxygen ( $= 2.39$  per cent) when the total copper is calculated as  $\text{CuO}$ .  $\text{Fe}_2\text{O}_3$  and heavy metals other than copper were absent.

A spectrographic examination was made on a Baird two meter grating instrument of part of the sample used in the first chemical analysis. The results of this examination are tabulated below. The writer is indebted to Mr. Rockwell Kent, III, for contributing these data.

$< 0.001\%$	= Sn, V
$< 0.01\%$	= Ca, Pb, Zn, Mo, Ti, Zr
$< 0.1\%$	= Al, Mn, Si, Mg, Ba
$> 1\%$	= Fe

*Composition.* The chemical constitution of paramelaconite presents an interesting problem. The atomic contents of the unit cell are derived and itemized in Table 8. Two alternative interpretations of the composition can be made: (1) That some of the oxygen positions in the structure are vacant. (2) That there is not a defect structure and the composition is  $\text{Cu}_{12}\text{Cu}_4\text{O}_{14}$ .

TABLE 8. OBSERVED ATOMIC CONTENTS OF THE UNIT CELL OF PARAMELACONITE

1.	2.	3.	4.	5.
Analysis No. 4	Molecular quotient	Atomic quotient	Observed cell contents. Mol. wgt. of cell = 1230	Observed cell contents adjusted to 16 total Cu atoms
CuO = 78.62	0.9888	Cu <sup>2</sup> = 0.9888	= 12.16	= 12.29
Cu <sub>2</sub> O = 21.38	0.1494	Cu <sup>1</sup> = 0.2987	= 3.67	= 3.71
100.00		O = 1.1382	= 14.00	= 14.15
			15.83	16

(1) *Oxygen-Defect Structure.* On this basis, the *ideal* cell contents must be either  $\text{Cu}_{16}\text{O}_{16}$  or  $\text{Cu}_{14}\text{Cu}_2\text{O}_{15}$ . The latter formulation is excluded because arrangements of this number of atoms can not be found which conform to the geometry of the space group. Accepting the ideal cell contents as  $\text{Cu}_{16}\text{O}_{16}$ , the actual cell contents of the defect structure may be written  $(\text{Cu}_{16-2x}\text{Cu}_{2x})\text{O}_{16-x}$ . The value of  $x$  in this formula is fixed by analysis no. 4, Table 7, as 1.85. The simplest formula is  $(\text{Cu}_{1-2x}\text{Cu}_{2x})\text{O}_{1-x}$ , where  $x = 0.116$ . In this view, paramelaconite may be described as a cupric oxide  $\text{CuO}$ , with an oxygen-defect structure in which the valence change accompanying the omission of oxygen atoms is compensated by the appearance of cuprous ions in place of some of the cupric copper. The cuprous copper is then proper but not essential to the crystal. Geometrical arrangements of the ideal cell contents  $\text{Cu}_{16}\text{O}_{16}$  can be found in both the space group of the true cell,  $I4/amd$ , and of the pseudo-cell,  $I4/mmm$ . The calculated specific gravity of the adjusted defect cell is 6.106, and the calculated specific gravity of the ideal cell is 6.25. Support for the validity of this interpretation of the composition would be afforded if additional occurrences of paramelaconite were found in which the postulated formulation was satisfied with different values of  $x$ . Definite proof, however, must await an analysis of the structure.

Defect structures with omissions among the anions are quite unusual. Ordinarily, the anions act as the "structure-supporters" and the omissions occur among the cations. Oxygen-defect structures, however, have been reported by Sillén and Aurivillius (1939) in the systems  $\text{PbO}-\text{Bi}_2\text{O}_3$  and  $\text{SrO}-\text{Bi}_2\text{O}_3$ . Anion-defect structures also occur between yttrifluorite and fluorite, and between the Sr and La analogues of these substances.

(2). *Non-Defect Compound,  $\text{Cu}_{12}\text{Cu}_4\text{O}_{14}$ .* Paramelaconite also may be represented as an oxide with both essential cuprous and cupric copper in definite ratio. The indicated formula is  $\text{Cu}_{12}\text{Cu}_4\text{O}_{14}$ . Cell contents with less or more than a total of 16 copper atoms or 14 oxygen atoms must be

excluded because of the marked differences then appearing between the observed and calculated specific gravities, as seen from Table 9.

TABLE 9. RELATION BETWEEN ATOMIC CONTENTS OF UNIT CELL AND CALCULATED SPECIFIC GRAVITY

Total Number of Copper Atoms	12	13	14	15	16	17	18	26
Corresponding No. of Oxygen Atoms	10.61	11.49	12.38	13.26	14.15	15.03	15.91	22.99
Calculated Specific Gravity	4.37	4.96	5.34	5.72	6.106	6.49	6.87	9.92

Total Number of Oxygen Atoms	12	13	14	15	16	17	18	23
Corresponding No. of Copper Atoms	13.57	14.71	15.84	16.97	18.10	19.23	20.36	26.02
Calculated Specific Gravity	5.18	5.61	6.04	6.48	6.91	7.34	7.77	9.92

Evidence bearing on the validity of this interpretation may be mentioned. The content of atoms in the cell must be that of whole numbers, within the experimental error. If the content is irrational the present interpretation must be denied. (The necessity for a whole number ratio of the cupric and cuprous ions would be obviated if these ions were structurally equivalent, but there would then appear to be no reason for maintaining the definite ratio between these ions required in the present case by the fixed number of oxygen atoms in the formula. Variation in the cuprous:cupric ratio would vary the total number of oxygen atoms and the case would become that of (1), previously discussed.) The observed number of cuprous atoms in the cell is only 3.71, but it is not entirely certain that this departure from the whole number 4 is beyond the experimental error. The per cent of copper in  $\text{Cu}_6\text{Cu}_2\text{O}_7$  is 81.95, which agrees quite closely with the directly determined value of 81.80. (See Table 7, columns 4, 5.) This difference is considered by the analyst to be beyond the limit of error of the determination in the present especially favorable case, but direct test of the accuracy in the way of duplicate determinations is lacking.

Geometrical arrangements of the cell contents  $\text{Cu}_{12}\text{Cu}_4\text{O}_{14}$  can not be found in the space group,  $I4/amd$ , of paramelaconite. It is assumed that the copper and oxygen atoms are non-equivalent. The only possible arrangements of the postulated cell contents in a ditetragonal-dipyramidal space group is in  $I4/mmm$ . This is the space group of the pseudo-cell, but this cell, which has one-eighth the volume of the true cell, could accommodate only fractional atoms. It appears, therefore, that the present basis of interpretation must be excluded and the mineral be represented



as an oxygen-defect cupric oxide. Interpretations based on interstitial solid solution, or on omissions in the copper positions, also must be discarded for reasons already indicated.

*Thermal Behavior.* Powdered paramelaconite was heated in evacuated Pyrex capsules in an electric furnace. Material from the sample used for analysis 4, Table 7, was employed for the purpose. The cooled product was examined by the *x*-ray powder method. An immediately reversible transformation would of course go unrecognized in this method. Material held at 365° C. for 2 hours gave the pattern of tenorite with a distinct superimposed pattern of cuprite and traces of the strongest lines of paramelaconite. Material held for 1 hour at 300° C. and another sample held for 5 hours at 240° C. gave a strong pattern of paramelaconite with a faint superimposed pattern of tenorite and traces of the strong lines of cuprite. A sample held for 40 hours at 190° C. gave superimposed patterns of about equal intensity of tenorite and paramelaconite with a faint pattern of cuprite. As far as could be judged the relative amounts of tenorite and cuprite in all of the above preparations was the same. The breakdown seemingly represents a simple dissociation of the cuprous and cupric copper of the original homogeneous oxide phase into admixed CuO and Cu<sub>2</sub>O. Paramelaconite of ideal composition (CuO), without vacant oxygen positions, presumably would break down to tenorite alone. A somewhat similar behavior has been found by Goldschmidt and Thomassen (1923) for the compound UO<sub>2</sub> (uraninite). The natural material is more or less oxidized to UO<sub>3</sub> but still maintains the original, fluorite-type, structure. The extra oxygen is thought to be in interstitial solid solution, occupying vacant NaCl-types positions in the structure. On heating, unoxidized UO<sub>2</sub> remains unchanged, but the oxidized material may break down in part to U<sub>3</sub>O<sub>8</sub>.

A small solid grain of paramelaconite was brought rapidly to dull red heat in air and immediately quenched. This grain gave a mixed *x*-ray pattern of tenorite and cuprite, identical in relative intensity with that of the material heated in vacuo. No lines of paramelaconite were found in this sample. It may be noted that the rate of breakdown increases very markedly with increasing temperature. If the fine powder is held at temperatures above dull red heat for an hour or so, a pronounced increase in the amount of admixed cuprite is observed. This effect probably is due to the dissociation of the CuO generated in the initial breakdown, since the reaction  $4 \text{ CuO} \rightleftharpoons 2 \text{ Cu}_2\text{O} + \text{O}_2$  goes to the right with increasing temperature. At ordinary pressure the reaction is said to go to completion at about 1050° C. It was found in this connection that ignited samples containing cuprite when left to stand in contact with air for a day or so completely oxidized to tenorite.

Wöhler and Foss (1906) contended that the  $\text{Cu}_2\text{O}$ , formed as the reaction  $4\text{CuO} \rightleftharpoons 2\text{Cu}_2\text{O} + \text{O}_2$  proceeds to the right, enters a solid solution with the  $\text{CuO}$  as a single phase. A later thermal study by Smyth and Roberts (1920) of this system showed that solid solubility between  $\text{Cu}_2\text{O}$  and  $\text{CuO}$  was non-existent or negligible. This conclusion is supported by the present  $x$ -ray observations. Paramelaconite could be interpreted as a solid solution of  $\text{CuO}$  and  $\text{Cu}_2\text{O}$  in the sense of these writers, on the basis of an oxygen-defect structure, but the mineral has of course been formed in a very different system and temperature range. The present observations also indicate that tenorite does not form an oxygen-defect structure over the temperature range investigated to an extent comparable to that of paramelaconite.

The crystallites of tenorite and cuprite formed in the breakdown are randomly oriented with respect to each other and to the original paramelaconite.  $X$ -ray rotation photographs taken about  $[001]$  and  $[100]$  of two heated single-crystals gave complete powder pictures of tenorite and cuprite with no evidence of layer-periodicities. A third crystal, heated briefly at about  $400^\circ \text{C}$ ., broke down only partially and gave definite layer-periods of paramelaconite with superposed powder patterns of tenorite and cuprite.

#### OCCURRENCE AND ASSOCIATION

The matrix of the specimens consists of goethite with a small amount of admixed cuprite and native copper. Upon this base is a thin botryoidal coating of radially fibrous goethite, which in part is overlain by black massive tenorite. Deposited directly upon this crust are the crystals of paramelaconite, which in turn support, and in part enclose, long prismatic crystals of connellite. Elsewhere the connellite rests directly upon the tenorite or goethite crust. Small crystals of cuprite are sometimes found completely embedded in the paramelaconite. It is clear that paramelaconite, connellite and cuprite were deposited contemporaneously for a brief period at least, and that the deposition of the connellite continued after the cessation of crystallization of the paramelaconite. The mineral succession was closed by the deposition of light greenish or silvery white felted flakes of a mineral identified by its  $x$ -ray pattern as malachite. The mineral succession may be summarized as:

(Matrix = goethite, cuprite, native copper)  $\rightarrow$  goethite  $\rightarrow$  tenorite  $\rightarrow$  paramelaconite (with minor cuprite and connellite)  $\rightarrow$  connellite  $\rightarrow$  malachite

$X$ -ray powder photographs were taken of specimens of the pulverulent or pitch-like black massive varieties of cupric oxide, usually termed melaconite, melanochalcite or copper pitch-ore, in hope of finding further

occurrences of paramelaconite. Of twelve specimens from seven localities, nine were found to consist of tenorite, and three to consist of delafossite. One of the occurrences of delafossite, from Eureka, Nevada, is new. The identity of melanochalcite and of copper pitch-ore in general with tenorite was urged by Hunt and Kraus (1916) and by Guild (1929) on optical and chemical grounds, and this view is here confirmed. Koenig, in the original description of paramelaconite, reported a second occurrence of the mineral as an impregnation of black crystals in a coarse sandstone. The locality was given only as Arizona. One of the two original specimens of this material was examined and proved to be tenorite.

#### ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Professor Harry Berman for his interest and aid throughout the investigation, to Dr. C. W. Wolfe for a discussion of the crystallographic and x-ray data, and to Dr. George Tunell, of the Geophysical Laboratory, Washington, D. C., for reading the manuscript. The writer also has had the opportunity to discuss aspects of the problem with Professor M. J. Buerger of the Massachusetts Institute of Technology.

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## NOTES AND NEWS

### SOME LITTLE-KNOWN MINERALS OF THE BEAR MOUNTAIN SECTION OF THE HUDSON HIGHLANDS, NEW YORK

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#### INTRODUCTION

Field work was carried on for two summer seasons by the junior author as Geologist of Trailside Museums, Bear Mountain, N. Y. This locality is in the Palisades Interstate Park, 50 miles north of New York City, on the Hudson River. Petrographic studies were made by the writers at the Geological Laboratory, University of Virginia. The purpose of this paper is to place on record several little-known minerals found in the area.

Bear Mountain is part of the relatively rugged upland known as the Highlands of the Hudson. The rocks of the region are ancient pre-Cambrian crystallines, which appear to be closely related to those of the Adirondack Mountains.

The oldest rocks are schists, gneisses, and marbles which are said by Berkey and Rice<sup>1</sup> to be of Grenville age. These highly metamorphosed sediments were intruded and replaced by a number of igneous rocks. From oldest to youngest, these include Pochuk diorite, Canada Hill granite, Storm King granite, and a swarm of basaltic and diabasic dikes.

#### MINERAL LOCALITY CONSIDERED

The location where the minerals to be discussed were found is in the valley of the mountain stream which connects Upper and Lower Twin Lakes. It is about five miles west of Bear Mountain, just off of Highway No. 6.

This locality was brought to the attention of the junior author when girls of a nearby camp brought for identification a number of shiny black octahedral crystals of pleonaste, collected from the river sand. Some of the crystals measured half an inch on an edge.

The source of this spinel placer was later found to be a low ledge of contact metamorphosed Grenville marble which had been cut by the stream. The marble at this locality consists chiefly of pink and white calcite, greenish-black pleonaste, and yellow chondrodite. A pyroxene (probably diopside), magnetite, and chlorite were shown by the microscope to be the accompanying minerals.

Pleonaste in thin section appears as a gray-green mineral with rounded outline, high relief, and an index of approximately 1.77. Imperfect octa-

<sup>1</sup> Berkey, Charles P., and Rice, Marion, *Geology of the West Point Quadrangle, N. Y.: New York State Museum, Bull. 225-226*, 49 (1921).

hedral cleavage can be seen in both the hand specimen and in thin section.

The presence of chondrodite was suggested by Mr. D. J. Cederstrom, of the United States Geological Survey, and its identification was checked by the senior author. In thin section in ordinary light, it appears as a colorless mineral with irregular form and a quadratic fracture. The lowest index is approximately 1.60. The double refraction is approximately 0.035, and the extinction angle measured on the cleavage is  $31^\circ$ . The data, together with the large optic axial angle, check rather closely with the determination made by Eskola.<sup>2</sup>

Across the stream from the outcrop of marble was found a ridge of dark-gray hornblende and pyroxene gneiss. The rock is of interest because it contains scapolite (mizzonite). The mineral occurs only in small amounts, and is best shown in thin section. In one instance it is associated with hornblende and pyrite, and in another it fills the spaces between augite crystals.

Optical investigation of the mineral in thin section yields the following information: under ordinary light it appears colorless, with irregular form, slight "twinkling," low relief, and the following indices of refraction:  $\omega = 1.575$ , and  $\epsilon = 1.55$ . Two cleavages can be seen and the angle between them is  $90^\circ$ . Under crossed nicols, the interference colors are second order blue, yellow, and green, with a double refraction of approximately 0.029. The extinction is parallel, and the mineral is uniaxial, optically negative. These observations check closely with scapolite of the composition of mizzonite.

#### ACKNOWLEDGMENTS

The writers wish to express their appreciation for assistance during the progress of the field work to Professor Joseph K. Roberts of the University of Virginia and Mr. William H. Carr, the Director of Trailside Museums. Grateful acknowledgment is also made to Mr. Rodney T. Bon-sall, Jr., for determining the optical properties of the minerals discussed above; to Mr. D. J. Cederstrom, of the United States Geological Survey, for valuable suggestions; and to Mr. Linwood H. Warwick, for editorial assistance.

<sup>2</sup> Eskola, Pentti, On contact between gneiss and limestone in western Massachusetts: *Jour. Geology*, 30, 270 (1922).

## PYROPE GARNET VS. RUBY SPINEL IN KANSAS

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### INTRODUCTION

Exposed igneous rocks in Kansas are rare; the few that do out-crop are limited to very small areas. One of these exposed igneous rock bodies near Stockdale (N. E.  $\frac{1}{4}$  S. E.  $\frac{1}{4}$  Sec. 23, T. 8 S., R. 6 E.) in Riley County, is a serpentinized peridotite. This basic rock contains ilmenite, phlogopite, and another mineral that has been called ruby spinel (1).

When the writer first saw the mineral, he suspected that it was pyrope garnet and set out to re-identify the mineral.

A search of geologic literature pertaining to the Stockdale locality has yielded very meager information. Facts about the so-called ruby spinel are even more scarce. Ruby spinel from Kansas is first mentioned in the literature about 1880. Mudge (2) reported the mineral from rock that he called a shale, in the northern part of Riley County; he did not recognize the rock as being igneous. He did not, however, mention any tests that he had made in ascertaining the identity of the mineral.

Failyer and Bailey (3) included ruby spinel from Riley County in their list of Kansas minerals. Professor Sperry (1) of Kansas State College was the first to identify the mineral in definite connection with the Stockdale rock. Carpenter (4) mentioned ruby spinel in a recent paper, but he probably based his identification on previous reports.

The writer visited the Stockdale area in 1940 and procured samples of the red mineral for study. A sample consisting of several grams of fragmentary material was submitted for chemical analysis, and the analysis at the outset confirmed the writer's contention that the mineral was not spinel, for silica was present in large amount.

DESCRIPTION OF MINERAL. Analyses have yielded the following results:

#### COMPOSITION OF RED MINERAL FROM IGNEOUS ROCK EXPOSED NEAR STOCKDALE, KANSAS

SiO <sub>2</sub>	40.42
Al <sub>2</sub> O <sub>3</sub>	21.12
Cr <sub>2</sub> O <sub>3</sub>	7.90
Fe <sub>2</sub> O <sub>3</sub>	10.50
MgO	14.42
CaO	4.71
<hr/>	
Total	99.07

A comparison of this analysis with those in Dana's *System of Mineralogy* (5) indicates that the mineral is similar to pyrope garnet. Of chief in-



terest, however, is the amount of chromium which is greater than in any analysis of pyrope garnet given in the tables.

Although the chemical analysis is conclusive proof that the mineral is pyrope garnet, some of the physical properties have likewise been measured. The hardness is 7.5, the specific gravity 3.47, and the refractive index 1.746.

The mineral is found in anhedral to subhedral phenocrysts in the serpentinized peridotite. Phenocrysts range from microscopic individuals to grains as much as one centimeter in diameter, but most of the larger masses are fractured, so that whole specimens of that size are uncommon. The mineral is red to reddish brown, transparent to translucent, and has a vitreous to resinous luster. Its streak is white, and its fracture is conchoidal to uneven. It is brittle to friable.

CONCLUSIONS. The chemical analysis proves beyond doubt that the tested specimens of red mineral from the Stockdale rock are pyrope garnet, but the writer does not imply that ruby spinel is absent from the rock. He concludes, however, that most, if not all, of the red mineral is pyrope garnet, and that any identification of a mineral from the Stockdale igneous body as ruby spinel must be verified.

ACKNOWLEDGMENTS. The writer expresses his thanks to Mr. Clarence Culbertson, chemist for the Kansas Geological Survey, for his analysis of the mineral, and to Mr. Ralph H. King for his help and criticism in the preparation of this paper.

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## SOME SOLUBLE CONSTITUENTS OF METEORITES

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No doubt the most frequently recognized water soluble constituent of meteorites is lawrencite ( $\text{FeCl}_2$ ) as it is doubtless responsible for the rusty spots so frequently seen on light colored stones. Its effect on irons is all too familiar to collectors. In spite of its commonness, such determinations as we have of the amount present are almost invariably calculated from the chlorine content. Since other chlorine compounds are sometimes present, such figures are likely to be too high. The largest amount so far reported is from the Mount Eldon (Arizona), graphite mass in which W. A. Sloane<sup>1</sup> found 1.980%. The writer found 1.64% by extraction with alcohol but some was lost.<sup>2</sup>

Numerous other water soluble salts have been reported from time to time. Thus the Lancé meteorite (France) is reported to contain 0.21% sodium chloride.<sup>3</sup> Maskelyne reported 0.44% calcium sulphate and 4.13% calcium sulphide in the Bustee stone (Oudh, United Provinces, India), while Dancer reported 0.76% sodium sulphide, 1.58% calcium sulphate and 0.01 calcium chloride in the same stone.<sup>4</sup> Berzelius reported 10.3% magnesium sulphate and vitriolic nickel (presumably nickel sulphate) in Alais (France) and Roscoe found 10.91%; Scheerer found sodium chloride in the Stannern stone (Moravia); and Shepard reported the sulphates of magnesium and sodium, the chlorides of calcium and magnesium, the hyposulphites of sodium and magnesium, and soluble silica in the Bishopville stone (South Carolina).<sup>5</sup> He also mentions that a sulphate of iron was found in the troilite of the Cosby Creek (Tennessee) iron. Baumhauer<sup>6</sup> reported a water soluble substance in the Knyahinya (Ruthenia) stone which reacted with turmeric paper.

Next to lawrencite, oldhamite is probably the best known of the water soluble meteoritic minerals. This mineral is an impure calcium sulphide which was discovered in the Bustee stone by Maskelyne<sup>7</sup> in a part of the stone which differs in other respects from the rest. Two analyses of the little nodules showed that it consisted of calcium sulphide plus about three per cent of magnesium sulphide. Calcium sulphate and carbonate, which were also found, were doubtless alteration products. He also reported it as somewhat doubtfully present in the Bishopville meteorite.

<sup>1</sup> *Am. Jour. Sci.*, (5), **21**, 173 (1931).

<sup>2</sup> *Pop. Astron.*, **48**, 561 (1940).

<sup>3</sup> See Flight, *Geol. Mag.*, *n.s.* **2**, 219-222 (1875).

<sup>4</sup> See Flight, *Geol. Mag.*, *n.s.* **2**, 408-411 (1875).

<sup>5</sup> *Am. Jour. Sci.*, (2), **2**, 348 (1846); **6**, 411-414 (1848).

<sup>6</sup> *Archives Neerlandaises* **7**, 146 (1872).

<sup>7</sup> *Brit. Assoc. Rept.*, App. **11**, 190 (1862); *Phil. Trans. London*, **160**, 195 (1870).

Borgstrom certainly found it in Hvittis (Finland); Brezina probably found it in Aubres (France); and it has been reported in Nagaya (Nogoya, Argentina?). Lacroix identified it by both optical and chemical means in the Saint-Sauveur stone (France),<sup>8</sup> and reported 1.15%.

Tassin found large quantities of calcium and sulphur in a fine powder derived from the Allegan (Michigan) stone.<sup>9</sup> Extraction with boiling water, however, gave only 0.064% of oldhamite and it could not be detected optically. According to Merrill,<sup>10</sup> G. Gilbert obtained CaO equivalent to 0.072% of CaS by extracting the Cullison (Kansas) stone with distilled water, and A. Blair using 1:50 HCl obtained 0.28% CaO and 0.05% SO<sub>4</sub>. If these constituents represent original oldhamite they correspond to 0.36 and 0.45%, respectively. On the other hand the mineral could not be found present optically. Merrill<sup>11</sup> digested twenty-five stones with boiling water and tested the extract for calcium. The result was positive in twenty cases, doubtful in one and negative in four. In the case of Pultusk, two samples gave a positive result and a third was negative. Later, Ochansk was reported to have given a negative test.<sup>12</sup>

The presence of calcium is interpreted as evidence of the presence of oldhamite but since other soluble calcium salts have been reported, the value of this research is impaired by failure to test the extract for sulphide or sulphate. When one of these meteorites, Alfianello (Italy), was thoroughly washed with water and then extracted with dilute hydrochloric acid, 0.03% CaO and 0.013% S were obtained. These values are equivalent to 0.030% of additional oldhamite. Oldhamite was detected by both optical and chemical methods in the Indarch stone (Russia). Extraction with water gave 0.464% CaO which is equivalent to 0.596% CaS. Its presence in Bishopville seems to be definitely established since Merrill<sup>13</sup> obtained calcium equivalent to 0.67% of oldhamite by extraction with water. The author confirms this to the extent of finding a strong calcium reaction in a water extract of Bishopville, and in addition he finds an equally strong reaction for sulphate.

The writer has digested thirteen stony meteorites, and associated minerals from iron meteorites, with boiling distilled water and tested the extracts for certain ions. Ammonium oxalate was used for calcium; ammonium thiosulphate for iron; dimethylglyoxime test paper for nickel; silver nitrate for chlorine; sodium nitroprusside for sulphide;

<sup>8</sup> *Compt. Rend.*, **177**, 561-563 (1908).

<sup>9</sup> *Proc. U. S. Nat. Mus.*, **34**, 433-434 (1908).

<sup>10</sup> *Proc. U. S. Nat. Mus.*, **44**, 330 (1913).

<sup>11</sup> *Proc. Nat. Acad. Sci.*, **1**, 302-308 (1915); **14**, 1st. mem., 25 (1925).

<sup>12</sup> *Proc. Nat. Acad. Sci.*, **14**, 4th mem., 8 (1925).

<sup>13</sup> *Proc. Nat. Acad. Sci.*, **14**, 1st. mem., 12-13 (1925).



barium chloride for sulphate; malachite green for sulphite; and molybdate reagent plus stannous chloride for phosphate. The results are given in the accompanying Table 1.

TABLE 1

Meteorite	Ca	Fe	Ni	Cl	PO <sub>4</sub>	S	SO <sub>4</sub>	SO <sub>3</sub>
Holbrook, Ariz.	++	?	—	—	++	—	++	
Richardton, N.D.	+		—	+				
Adrian, Tex. I	+		—	+	?	—		
Adrian, Tex. II	+	—	—	+	—	—		
Tyron, Nebr.	++	—	—	+++	—	—		
Gretna, Kans.	+	—	?	—	—	—	—	
Bishopville, S.C.	+++	—	—	—	—	—	+++	
Plainview, Tex.	—	—	—	—	?	—	+	—
Allegan, Mich.	—	—	—	—	+	—	?	—
Amalia Farm graphite	—	—	?	+	—	—	+	
Mt. Eldon graphite	—	+++	++	+++		—		
Canyon Diablo, troilite	—	—	?	—	?	—	?	—
Xiquipilco, troilite	—	—	?	?	+	—	+++	—

A blank indicates that the test was not made; a minus sign indicates a negative reaction; a question mark indicates a doubtful reaction; and the approximate strength of a positive result is indicated by one, two or three plus signs.

The positive results for phosphate are of interest. As far as I can determine they are the first ones to be obtained using a neutral solvent. Merrill has obtained positive results on several meteorites, but he used dilute acid and attributes the result to the solution of apatite, or a similar mineral. The Richardton, the two Adrian and the Tyron stones, apparently contain calcium chloride. (The Adrian and some of the other stones have not yet been described.) The calcium sulphate indicated in the Bishopville meteorite is probably derived from the oxidation of oldhamite.

Extraction of meteorites with organic solvents has yielded interesting results, and the origin of the organic compounds obtained is puzzling to say the least. The only definitely identifiable product however is free sulphur. Wöhler<sup>14</sup> obtained it from Cold Bokkeveld (South Africa), and from Kaba (Hungary). Roscoe<sup>15</sup> found 1.24% of free sulphur in Alais (France). Shepard<sup>5</sup> reported visible grains of sulphur in Bishopville and

<sup>14</sup> *Sitzber. Wien Akad. Wiss.*, (1863); *Phil. Mag.*, 25, 319.

<sup>15</sup> *Proc. Lit. Phil. Soc. Manchester*, Feb. 24 (1863); *Phil. Mag.*, 25, 319.

this was confirmed by Reichenbach.<sup>16</sup> Flight<sup>17</sup> extracted the powdered troilite of the Cranbourne (Australia) iron with carbon disulphide and obtained 0.0207% of free sulphur. Wright<sup>18</sup> obtained a yellow deposit when he heated Cold Bokkeveld in a vacuum. He regarded this as sulphur and states that Ramelsberg also obtained sulphur from this stone, thus confirming Wöhler's result. Dewar and Ansdell<sup>19</sup> found small pieces of free sulphur floating on the water they obtained by heating Orgueil (France). The sulphur reported in the last two cases may have been derived from the decomposition of some other compound, although Smith<sup>20</sup> obtained free sulphur from Orgueil by extraction with carbon disulphide. He also believed that he had found free sulphur in the graphite of the Cosby Creek (Tennessee), the Cranbourne (Australia), and the Smithville (Tennessee) irons.

The writer has examined all of the meteorites in the above table for free sulphur using the sensitive pyridine-caustic soda test.<sup>21</sup> In addition, I have examined the Cuero and Kimble Co. (Texas) stones which were kindly supplied by Dr. Virgil E. Barnes of the University of Texas; a piece of the terrestrial troilite from Del Norte Co., California, and a sample of pyrrhotite from Sudbury, Ontario. Since it is possible to make rough estimates of the amount of sulphur present when using this test I record some rather crude estimates of the percentages of free sulphur in the various samples as follows:

Specimen	Sulphur content
Cuero, Texas	None
Kimble Co., Texas	Doubtful trace
Amalia Farm graphite	0.000X%
Mt. Eldon graphite	0.000X%
Canyon Diablo troilite	0.00000X%
Xiquipilco troilite	0.00000X%
Bishopville, S.C.	1.5%
California troilite	0.00000X%
Sudbury pyrrhotite	0.0X%

All of the rest contained no free sulphur. The accuracy of these estimates is low. It is possible that they are as much as ten fold too small, except for the Bishopville stone.

<sup>16</sup> *Study* **13**, 364 (1865).

<sup>17</sup> *Phil. Trans.*, no. **171**, 893-896 (1882); *Geol. Mag.*, n.s. **10**, 59-65 (1883).

<sup>18</sup> *Am. Jour. Sci.*, (3), **12**, 165-176 (1870).

<sup>19</sup> *Proc. Roy. Soc., London, Sec. A*, **40**, 549-559 (1886).

<sup>20</sup> *Am. Jour. Sci.*, (3), **11**, 388-393; 433-435 (1876).

<sup>21</sup> *Ind. and. Eng. Chem.*, (Anal. Ed.), **12**, 368 (1940).



## NEW DATA: DISCREDITED SPECIES

### REDIFINITION OF VARULITE AND ARROJADITE

(SODA-TRIPHYLITE = HEADDENITE) = ARROJADITE

BRIAN MASON: Minerals of the Varuträsk pegmatite, XXIII. Some iron-manganese phosphate minerals and their alteration products, with special reference to material from Varuträsk, *Geol. För. Förh.*, **63**, 117–175 (1941).

Recalculation of the seven available analyses of varulite and arrojadite lead to the formula  $(\text{Na}_2, \text{Ca})(\text{Mn}, \text{Fe})_2(\text{PO}_4)_2$ . The analyzed material, except for one sample, shows partial oxidation to ferric iron, with accompanying loss of sodium. The name varulite applies to material with  $\text{Mn} > \text{Fe}$ ; the name arrojadite to material with  $\text{Fe} > \text{Mn}$ . Arrojadite was first analyzed in 1891 by Headden, who did not name it. The name soda-triphyllite proposed for this material (Ziegler, 1914) is rejected on the ground of its being false in signification (natrophilite = soda-triphyllite). The name arrojadite (Guimaraes, 1925) has priority over the name headdenite (Quensel, 1937).

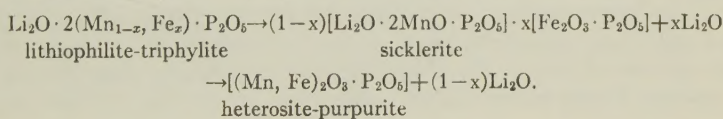
MICHAEL FLEISCHER

### REDEFINITION OF SICKLERITE

PSEUDOHETEROSITE = SICKLERITE

BRIAN MASON, *op. cit.*

The oxidation of lithiophilite-triphyllite is shown to proceed in two stages:—



Sicklerite may have either iron or manganese predominating, depending on the composition of the primary mineral. The names ferrisicklerite (Fe-sicklerite) and manganese-sicklerite (Mn-sicklerite) are suggested. Fourteen localities for sicklerite are listed. Pseudoheterosite (Lacroix, 1910) is shown to be ferri-sicklerite. Lacroix's name has priority over sicklerite (Schaller, 1912), but his description was incomplete and partially erroneous, and the name should be dropped.

M. F.

(PSEUDOTRIPLITE, MELANCHLOR, NEOPURPURITE) = HETEROSITE

(NA-PURPURITE, NA-HETEROSITE) = PURPURITE + ALLUAUDITE

BRIAN MASON, *op. cit.*

The names heterosite (Vauquelin, 1825) and purpurite (Graton and Schaller, 1905) are accepted for the Fe-rich and Mn-rich, respectively, members of the series  $(\text{Fe}, \text{Mn})\text{PO}_4$ . The water content (2–7%) is lost at 200° C. with no change in x-ray photographs, and is therefore regarded as nonessential. Pseudotriplite (Fuchs, 1835) and neopurpurite (de Jesus, 1933) are shown to be heterosite; melanchlor (Fuchs 1839) is a complex mixture containing sicklerite, heterosite and other minerals. Na-heterosite and Na-purpurite (Quensel, 1937) are shown by x-ray study to be mixtures of alluaudite and purpurite. These names should be dropped.

## PSEUDOPALAITE = PALAITE (= HUREAULITE?)

BRIAN MASON, *op. cit.*

An x-ray photograph of pseudopalaite (de Jesus, 1933) from the type locality in Portugal was identical with that given by palaite (Schaller, 1912) from Pala, Cal. Type hureaulite was not available for x-ray study, but comparison of physical and chemical properties suggests that hureaulite and palaite are identical. The name hureaulite (1854) has priority.

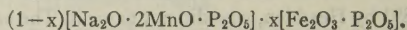
M. F.

## REDEFINITION OF ALLUAUDITE

LEMNÄSITE = ALLUAUDITE

BRIAN MASON, *op. cit.*

It is shown that the oxidation of the Na minerals varulite-arrojadite and natrophillite takes place in two stages, the first stage involving oxidation of Fe only, giving alluaudite; the second stage being the oxidation of Mn, giving heterosite-purpurite. Alluaudite is therefore the sodium analogue of sicklerite, and its formula is



X-ray study shows that lemnäsite (Pehrman, 1939) from Lemnäs, Finland, is identical with with type alluaudite (Damour, 1848) from Chanteloube, France.

M. F.